HAMPTON ROADS TRANSIT

U.S. Department of Transportation
Federal Transit Administration

Draft Environmental Impact Statement

# VIRGINIA BEACH TRANSIT EXTENSION STUDY

## Appendix Q

*Noise and Vibration Technical Report*




**February 2015**

Cover image: courtesy of the City of Virginia Beach

# Table of Contents

## 1.0 Introduction

HDR Engineering, Inc. (HDR) performed a noise and vibration impact assessment on behalf of Hampton Roads Transit (HRT) for the Virginia Beach Transit Extension Study (VBTES). The assessment followed guidance in FTA's Transit Noise and Vibration Impact Assessment document dated May 2006 (also referred to as the FTA manual). The VBTES evaluated alternatives to extend fixed guideway transit service from The Tide's Newtown Road Station in Norfolk east to the Oceanfront in Virginia Beach, Virginia. This noise and vibration assessment considers four alignment alternatives for light rail transit (LRT) and bus rapid transit (BRT) modes:

- Alternative 1A (Town Center Alternative) – Newtown Road Station to Town Center Station via the former Norfolk Southern Railway (NSRR) right-of-way (ROW)
- Alternative 1B (Rosemont Alternative) – Newtown Road station to Rosemont station via the former NSRR ROW
- Alternative 2 (NSRR Alternative) – Newtown Road Station to Oceanfront Station via the former NSRR ROW, Birdneck Road, Virginia Beach Boulevard, and 19th Street
- Alternative 3 (Hilltop Alternative) – Newtown Road Station to Oceanfront Station via the former NSRR ROW, Laskin Road, Birdneck Road, and 19th Street

All of the Town Center and Rosemont alternatives and the majority of the NSRR and Hilltop alignments are semi-exclusive fixed guideway systems for both LRT and BRT modes, with at-grade crossings limited to designated locations. The easternmost portions of the NSRR and Hilltop alternatives would include some segments where the track or bus lane is located in the roadway median with crossings at intersections with traffic signals, or BRT buses would operate in mixed traffic.

In addition to the LRT/ BRT alignment alternatives, three new feeder bus routes are proposed. The feeder buses will travel on city streets in the same manner as existing HRT bus routes, and they would include stops at LRT/BRT stations. The three proposed routes are as follows:

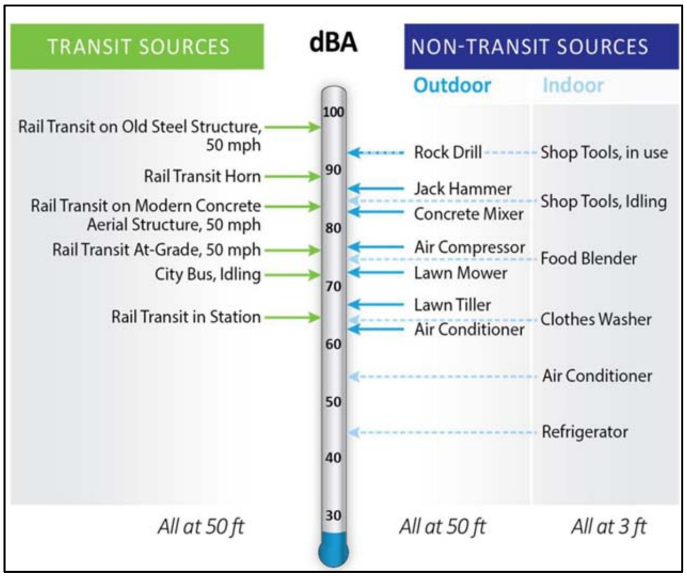
- Route 38: Greenbrier Mall to Witchduck station via Greenbrier Parkway, Volvo Parkway, Kempsville Road, and South Witchduck Road
- Route 39: Sentara Princess Anne Hospital to Pacific Avenue and 19th Street (Oceanfront Resort Area) via South Rosemont Road, Lynnhaven Parkway, Virginia Beach Boulevard, Laskin Road, and Atlantic Avenue
- Route 35: Sentara Virginia Beach General Hospital to Dam Neck Annex via Old Donation Parkway, North Great Neck Road, London Bridge Road, Potters Road, South First Colonial Road, Oceana Boulevard, General Booth Boulevard, and Dam Neck Road

Routes 38 and 39 are proposed to be implemented with all LRT or BRT alternatives. Route 35 would be a part of Alternatives 2 or 3 only.

## 1.1 Noise

Noise is unwanted or undesirable sound. Sound travels through the air as waves of tiny air pressure fluctuations caused by vibration. The intensity or loudness of a sound is determined by how much the sound pressure fluctuates. For convenience, sound pressure is expressed in decibel (dB) notation. Most sounds consist of a broad range of sound frequencies, from low frequencies to high frequencies. The average human ear does not perceive all frequencies equally. Therefore, the A-weighting scale was developed to approximate the way the human ear responds to sound levels; it mathematically applies less “weight” to frequencies we do not hear well, and applies more “weight” to frequencies we do hear well. Typical A-weighted noise levels for various types of sound sources are summarized in **Figure 1**.

**Figure 1 | Common Noise Sources**




*Source:* FTA, 2006

The equivalent average sound level ($L_{eq}$) is often used to describe sound levels that vary over time, usually a one-hour period. The $L_{eq}$ is often described as the constant sound level that is an equivalent exposure level to the actual time-varying sound level over the period (hour). Using 24 consecutive one hour $L_{eq}$ values, it is possible to calculate daily cumulative noise exposure. A common community noise rating is the Day-Night Average Sound Level (DNL or $L_{dn}$). The $L_{dn}$ is the 24-hour $L_{eq}$ but includes a ten dBA penalty on noise that occurs during the nighttime hours (between 10 p.m. and 7 a.m.) when sleep interference might be an issue. The 10-dBA penalty makes the $L_{dn}$ useful when assessing noise in residential areas, or land uses where overnight sleep occurs.

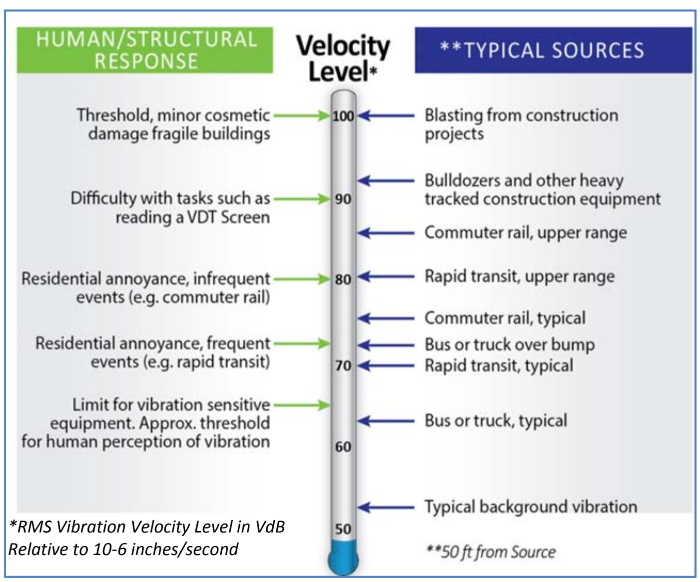
## 1.2 Vibration

Vibration consists of rapidly fluctuating motions. However, human response to vibration is a function of the average motion over a longer (but still short) time, such as one second. The root mean square (RMS) amplitude of a motion over a one-second period is commonly used to predict human response to vibration. For convenience, decibel notation is used to describe vibration relative to a reference quantity. The FTA has adopted the notation VdB (for vibration decibels), which is decibels relative to a reference quantity of one microinch per second ($10^{-6}$ in/s).

Ground-borne vibration (GBV) can be a serious concern for residents or at facilities that are vibration-sensitive, such as laboratories or recording studios. The effects of ground-borne vibration include perceptible movement of building floors, interference with vibration sensitive instruments, rattling of windows, and the shaking of items on shelves or hanging on walls. Additionally, GBV can cause the vibration of room surfaces resulting in ground-borne noise (GBN). Ground-borne noise is typically perceived as a low frequency rumbling sound.

In contrast to airborne noise, ground-borne vibration is not an everyday experience for most people. The background vibration level in residential areas is usually 50 VdB or lower—well below the threshold of perception for humans, which is around 65 VdB. Levels at which vibration interferes with sensitive instrumentation, such as medical imaging equipment or extremely high-precision manufacturing, can be much lower than the threshold of human perception. Most perceptible indoor vibration is caused by sources within a building such as the operation of mechanical equipment, movement of people, or slamming of doors. Typical outdoor sources of perceptible ground-borne vibration are construction equipment, steel-wheeled trains, and traffic on rough roads, though in most soils GBV dissipates very rapidly. **Figure 2** illustrates common vibration sources and the human and structural response to ground-borne vibration.

**Figure 2 | Typical Vibration Levels**




*Source:* FTA, 2006

# 2.0 Noise Impact Assessment Methodology

## 2.1 Approach

HDR used the Federal Transit Administration (FTA) screening-level approach to determine the impact of noise from the proposed light rail transit (LRT) and bus rapid transit (BRT) systems of the four build alternatives. The FTA's criteria for the noise screening-level assessment are based on the land use category of the building or receptor, existing noise levels, and change in noise exposure due to the project. The approach consists of:

1. Identifying land use categories and locations of noise receptors along the alignments
2. Measuring/modeling existing noise levels for the various land use categories and receptors
3. Modeling the future transit operational noise exposure for each build alternative
4. Verifying that the model reasonably predicts the operational noise exposure

**Table 1** summarizes Table 3-2 from the FTA manual, which describes the land use categories and the appropriate noise metrics.

**Table 1 | Noise Assessment Land Use Categories**

| Land Use Category | Noise Metric, dBA | Description of Land Use Category |
|---|---|---|
| 1 | $L_{eq}(h)$* | Quiet is an essential element: amphitheaters, concert pavilions, outdoor historic landmarks, recording studios, and concert halls |
| 2 | $L_{dn}$ | Residences and buildings where people normally sleep |
| 3 | $L_{eq}(h)$* | Institutional land uses with primarily daytime and evening use |

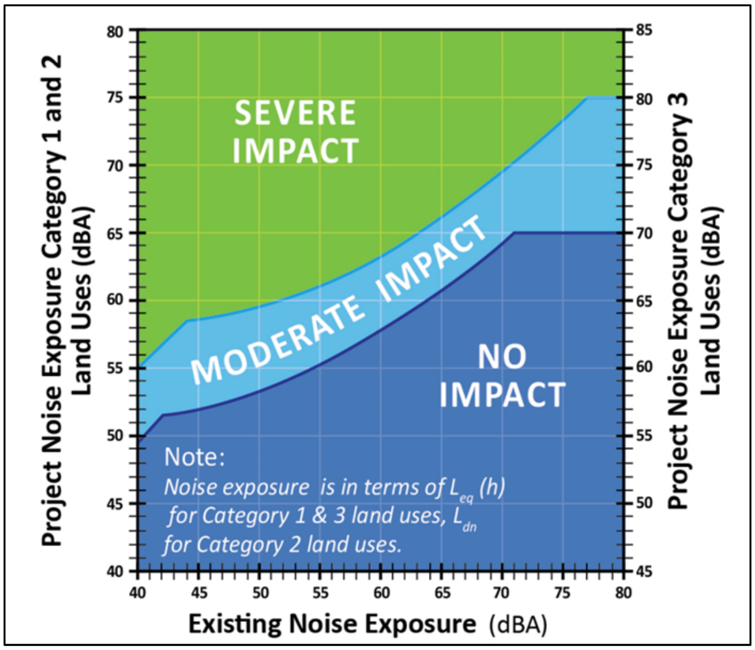
*$L_{eq}$ for the noisiest hour of transit-related activity during hours of noise sensitivity

*Source:* FTA, 2006

Note that different noise metrics are used depending on the land use category. Existing noise levels, project noise levels, and criteria are $L_{dn}$ levels for category 2 and $L_{eq}(h)$ levels for categories 1 and 3.

**Figure 3** illustrates the curves used to determine noise impacts based on the land use category, existing noise levels, and project noise exposure (Figure 3-1 of the FTA manual).

**Figure 3 | Project Noise Impact Curves**

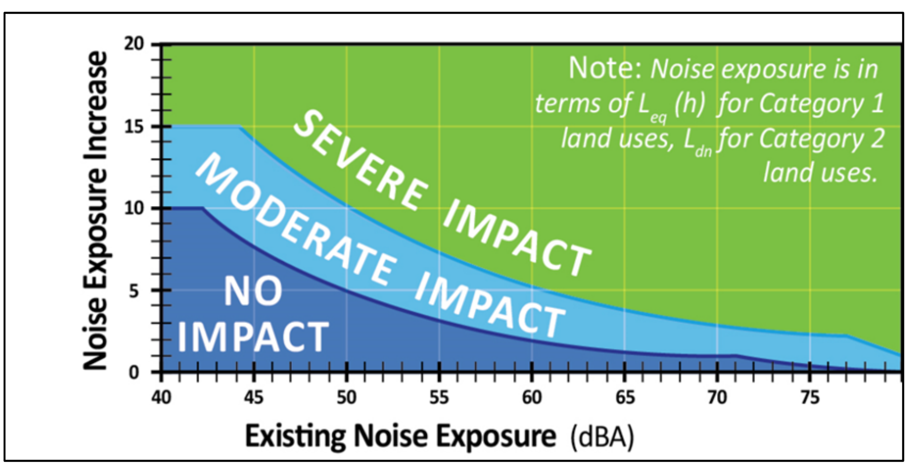



*Source:* FTA, 2006

According to the FTA, moderate noise impacts are considered to be noticeable by most people, and severe noise impacts are considered to be an annoyance to a significant percentage of people. The equations for the moderate and severe impact curves are given in Appendix B of the FTA manual.

Figure 3 presents the noise impact criteria in terms of project-related noise; the curves are based on increases in cumulative noise levels. As existing noise levels increase, the amount of additional noise necessary to adversely affect the receptor decreases. To illustrate how existing and cumulative noise levels are used to assess impacts, FTA created **Figure 4** (Figure 3-2 of the FTA manual).

**Figure 4 | Cumulative Noise Impact Curves**




*Source:* FTA, 2006

Virginia Beach City Code Section 23-69 states the maximum sound levels for residential buildings. The sound level measured inside a residence cannot exceed 55 dBA at night (10 pm to 7 am) and 65 dBA during the day (7 am to 10 pm). The measurement shall be made at least four feet from the wall nearest the sound source with all windows and doors closed. However, Section 23-69(d)(8) states that public transportation is exempt from the daytime maximum sound level. Modeling of indoor noise levels was not done as part of this assessment.

### 2.1.1 Inventory of Noise-Sensitive Sites

HDR used three techniques to identify noise-sensitive land uses in the study area. First, HDR reviewed aerial photographs with the alternative alignments overlaid upon them. Second, HDR reviewed publicly available and reasonably obtainable information online to look for special land uses (i.e. recording studios, broadcast studios, certain medical facilities, etc.). Third, HDR performed a visual/windshield survey of the study area and spoke with individuals in the study area. The goal of these three techniques was to identify noise-sensitive land uses that can be used to represent other noise-sensitive land uses in their immediate vicinity. Another goal of these techniques was to determine if there are any land uses that are especially sensitive to noise (i.e. recording studios, broadcast studios, etc.) in the study area. Based on this review, numerous noise-sensitive land uses were identified in the study area for use in this assessment.

**Table 2** presents the list of noise-sensitive receptors, the land use category they are in, and which alternatives they are a part of. **Figures 5 through 8** also show the locations of these noise-sensitive receptors relative to the proposed alternative alignments.

**Table 2 | Noise-Sensitive Receptors for the LRT/BRT Alternatives**

| Receptor | Land Use Category | Alts. | Receptor | Land Use Category | Alts. | Receptor | Land Use Category | Alts. |
|---|---|---|---|---|---|---|---|---|
| R1 | 2 | 1A,1B,2,3 | R19 | 2 | 1B,2,3 | R41 | 2 | 2 |
| R2 | 2 | 1A,1B,2,3 | R20 | 2 | 1B,2,3 | R42 | 2 | 2 |
| R3 | 3 | 1A,1B,2,3 | R21 | 2 | 1B,2,3 | R43 | 2 | 2 |
| R4 | 2 | 1A,1B,2,3 | R22 | 2 | 1B,2,3 | R44 | 2 | 2 |
| R5 | 2 | 1A,1B,2,3 | R23 | 3 | 1B,2,3 | R45 | 3 | 2 |
| R5a | 3 | 1A,1B,2,3 | R24 | 2 | 1B,2,3 | R46 | 2 | 2 |
| R6 | 2 | 1A,1B,2,3 | R25 | 2 | 2,3 | R47 | 2 | 2 |
| R7 | 3 | 1A,1B,2,3 | R26 | 2 | 2,3 | R48 | 2 | 2,3 |
| R8 | 2 | 1A,1B,2,3 | R27 | 2 | 2,3 | R49 | 2 | 2,3 |
| R9 | 3 | 1A,1B,2,3 | R28 | 3 | 2,3 | R50 | 2 | 2,3 |
| R10a | 1 | 1A,1B,2,3 | R29 | 2 | 2,3 | R51 | 2 | 2,3 |
| R10b | 1 | 1A,1B,2,3 | R30 | 3 | 2,3 | R52 | 2 | 2,3 |
| R10c | 3 | 1A,1B,2,3 | R31 | 2 | 2,3 | R53 | 2 | 2,3 |
| R10d | 1 | 1A,1B,2,3 | R32 | 3 | 2,3 | R54 | 2 | 2,3 |
| R11 | 2 | 1A,1B,2,3 | R33 | 2 | 2,3 | R56 | 2 | 2,3 |
| R12 | 2 | 1A,1B,2,3 | R34 | 3 | 2,3 | R58 | 2 | 3 |
| R13 | 3 | 1A,1B,2,3 | R35a | 2 | 2 | R59 | 2 | 3 |
| R14 | 2 | 1A,1B,2,3 | R35b | 2 | 2,3 | R60 | 2 | 3 |
| R15 | 2 | 1B,2,3 | R36 | 2 | 2 | R61 | 2 | 3 |
| R16 | 2 | 1B,2,3 | R37 | 3 | 2 | R62 | 2 | 3 |
| R17a | 2 | 1B,2,3 | R38 | 2 | 2 | R63 | 2 | 3 |
| R17b | 2 | 1B,2,3 | R39 | 2 | 2 | | | |
| R18 | 2 | 1B,2,3 | R40 | 2 | 2 | | | |

*Source:* HDR, Inc.

Receptors are not included for the area around the Newtown Road station, as the station is considered a part of the existing conditions. The station is part of The Tide light rail system that HRT currently operates in Norfolk. While the proposed project would increase transit vehicle traffic and feeder bus traffic at the Newtown Road station, a sound barrier is currently located between the station and nearby noise-sensitive receptors. This barrier is expected to handle increased sound levels from the proposed project.

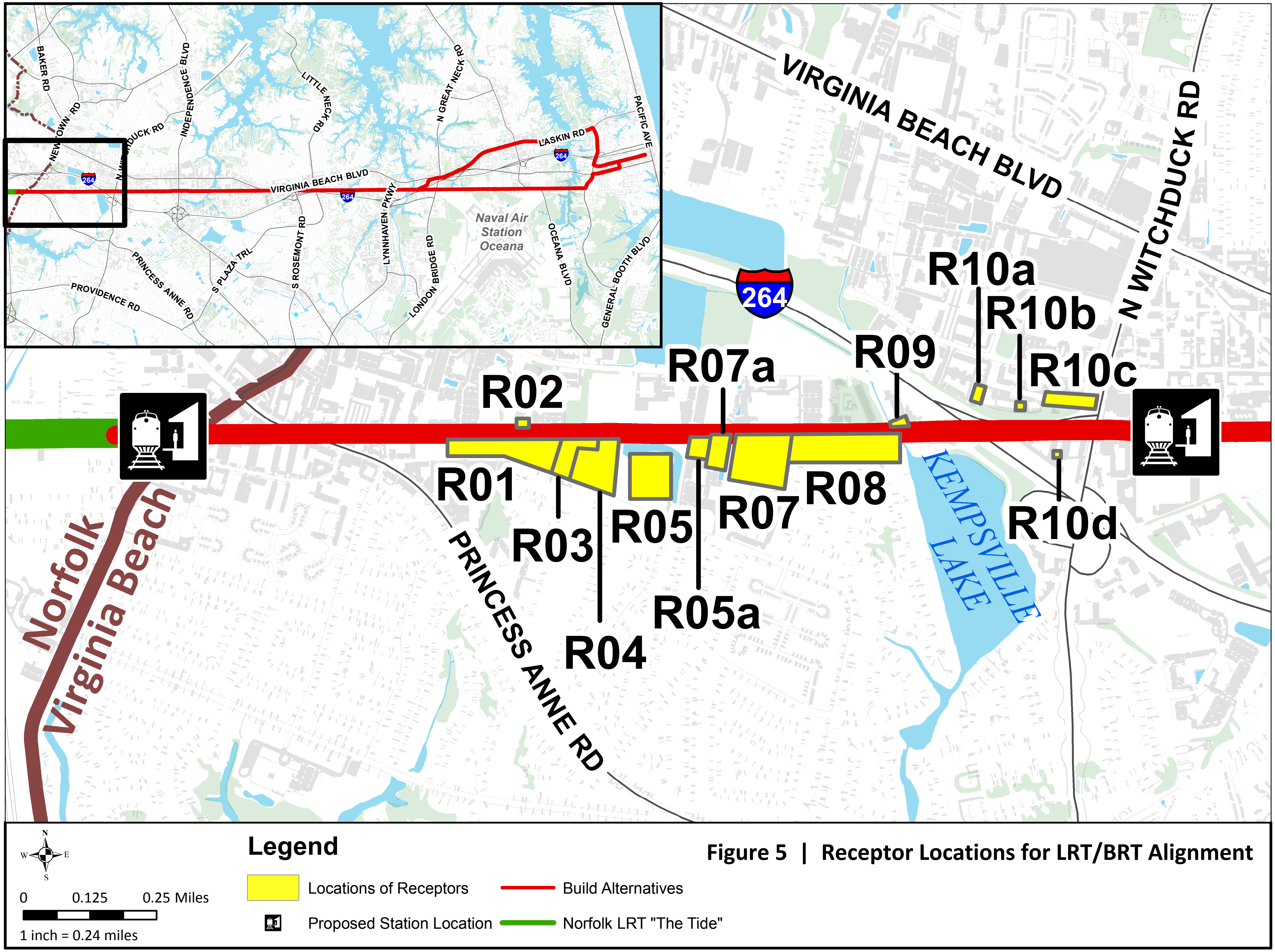
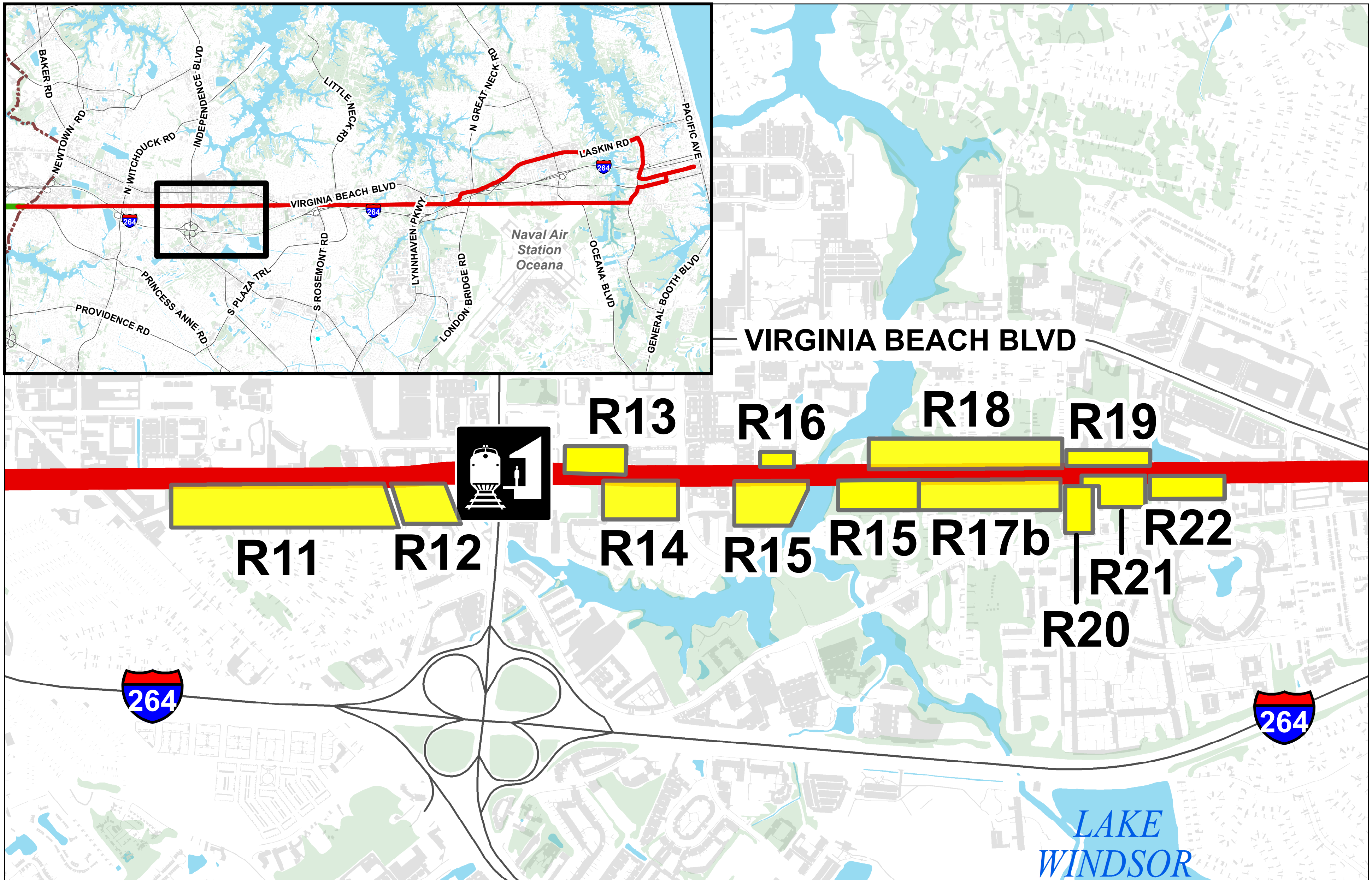



**Figure 5 | Receptor Locations for LRT/BRT Alignment**




N E S W

0 0.125 0.25 Miles

1 inch = 0.24 miles

**Legend**

Locations of Receptors

Proposed Station Location

Build Alternatives

Norfolk LRT "The Tide"

**Figure 6 | Receptor Locations for LRT/BRT Alignment**

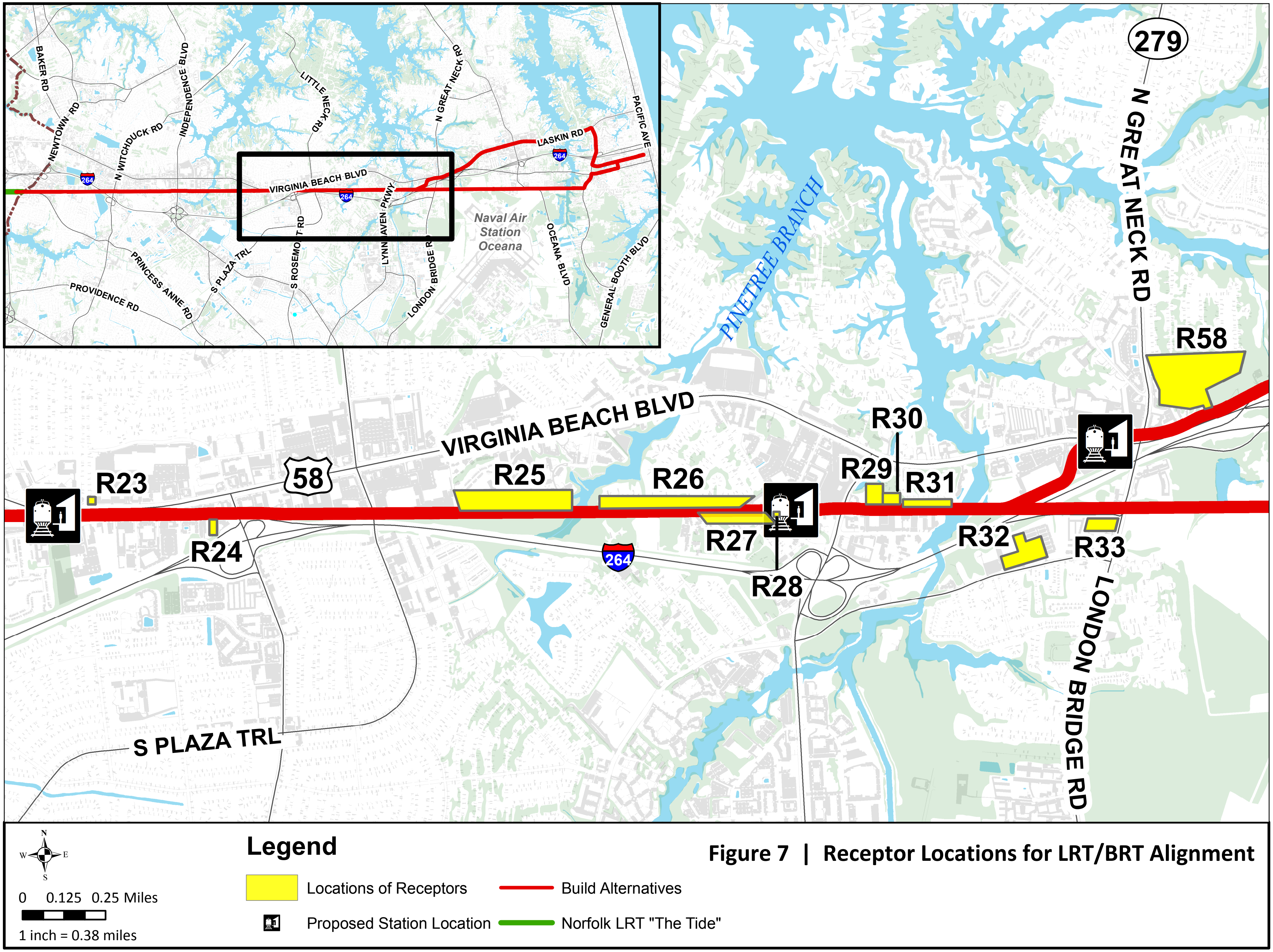



**Figure 7 | Receptor Locations for LRT/BRT Alignment**

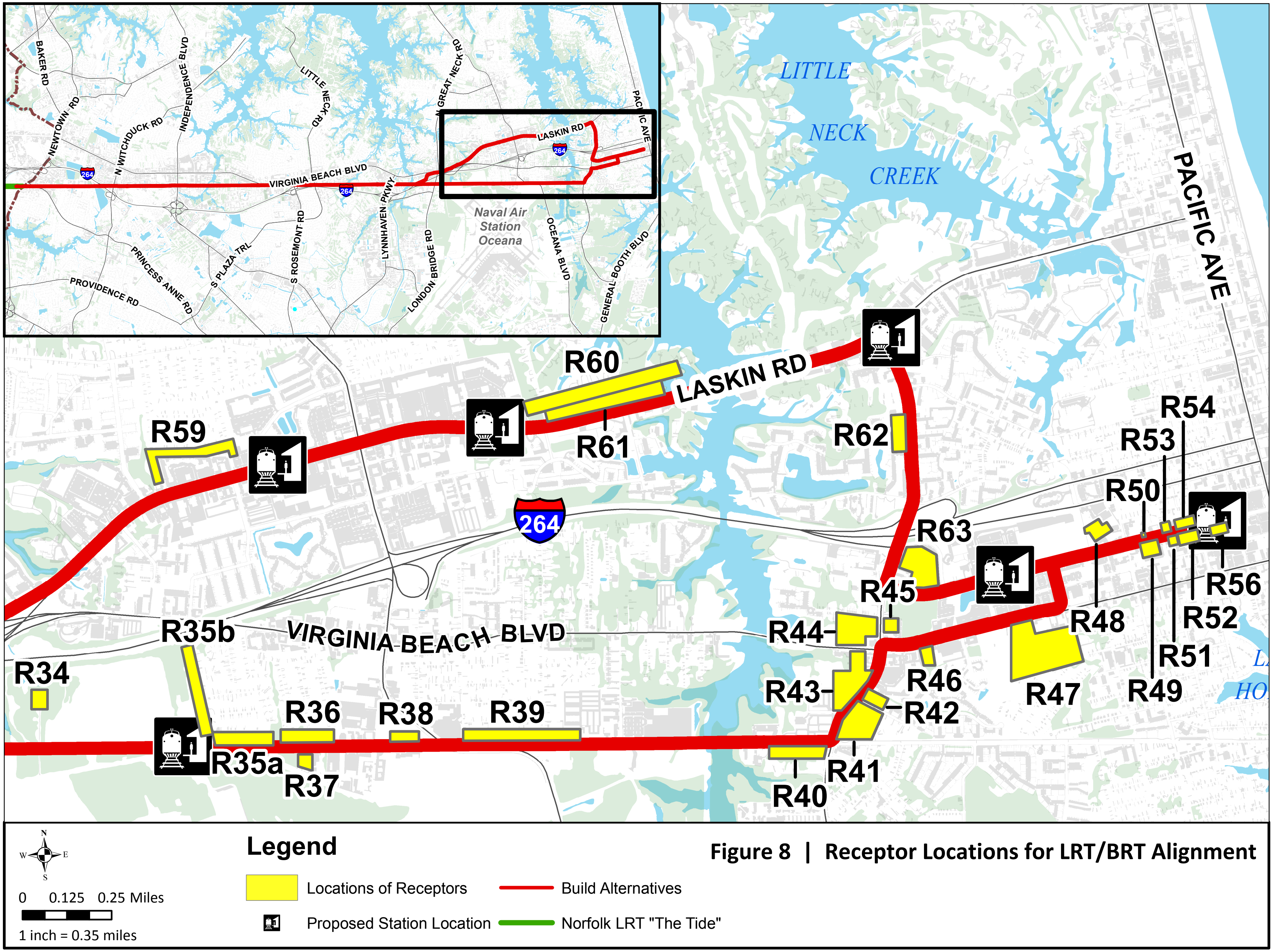



**Figure 8 | Receptor Locations for LRT/BRT Alignment**

**Table 3** lists the noise-sensitive receptors identified along feeder bus Route 38. **Figure 9** shows the locations of these receptors.

**Table 3 | Noise-Sensitive Receptors for Feeder Bus Route 38**

| Receptor | Land Use Category | Receptor | Land Use Category | Receptor | Land Use Category |
|---|---|---|---|---|---|
| 38-R01 | 3 | 38-R22 | 3 | 38-R43 | 2 |
| 38-R02 | 2 | 38-R23 | 2 | 38-R44 | 2 |
| 38-R03 | 2 | 38-R24 | 3 | 38-R45 | 3 |
| 38-R04 | 2 | 38-R25 | 3 | 38-R46 | 2 |
| 38-R05 | 2 | 38-R26 | 2 | 38-R47 | 2 |
| 38-R06 | 3 | 38-R27 | 2 | 38-R48 | 3 |
| 38-R07 | 2 | 38-R28 | 2 | 38-R49 | 2 |
| 38-R08 | 3 | 38-R29 | 2 | 38-R50 | 2 |
| 38-R09 | 3 | 38-R30 | 2 | 38-R51 | 3 |
| 38-R10 | 2 | 38-R31 | 2 | 38-R52 | 3 |
| 38-R11 | 2 | 38-R32 | 3 | 38-R53 | 3 |
| 38-R12 | 2 | 38-R33 | 2 | 38-R54 | 2 |
| 38-R13 | 2 | 38-R34 | 3 | 38-R55 | 3 |
| 38-R14 | 2 | 38-R35 | 2 | 38-R56 | 2 |
| 38-R15 | 2 | 38-R36 | 3 | 38-R57 | 1 |
| 38-R16 | 2 | 38-R37 | 2 | 38-R58 | 2 |
| 38-R17 | 3 | 38-R38 | 2 | 38-R59 | 2 |
| 38-R18 | 2 | 38-R39 | 2 | 38-R60 | 2 |
| 38-R19 | 3 | 38-R40 | 2 | 38-R61 | 3 |
| 38-R20 | 2 | 38-R41 | 2 | | |
| 38-R21 | 2 | 38-R42 | 2 | | |

*Source:* HDR, Inc.

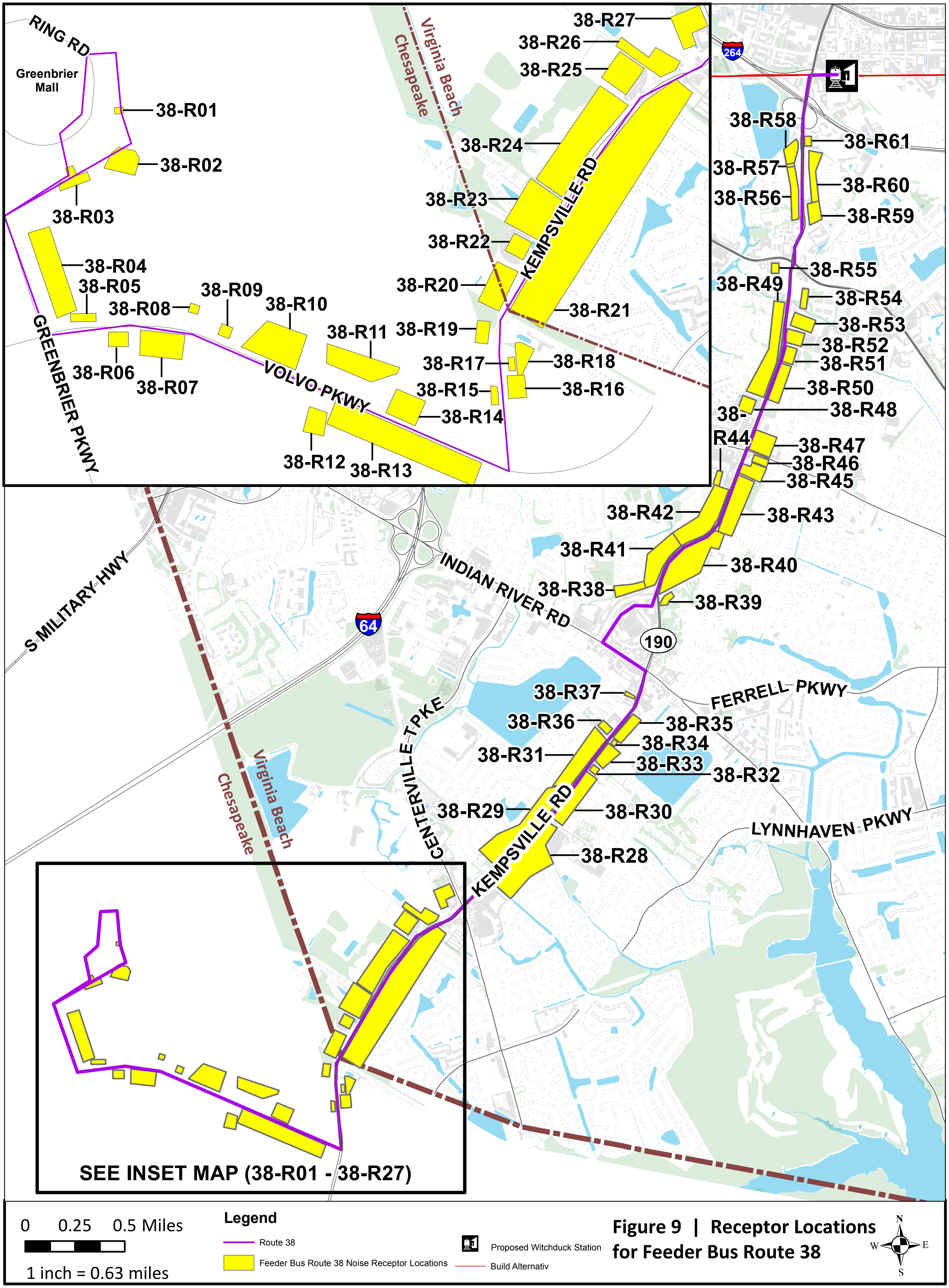



**Figure 9 | Receptor Locations for Feeder Bus Route 38**

**Table 4** lists the noise-sensitive receptors identified along feeder bus Route 39. **Figure 10** shows the locations of these receptors.

**Table 4 | Noise-Sensitive Receptors for Feeder Bus Route 39**

| Receptor | Land Use Category | | Receptor | Land Use Category | | Receptor | Land Use Category |
|---|---|---|---|---|---|---|---|
| 39-R01 | 3 | | 39-R16 | 2 | | 39-R31 | 2 |
| 39-R02 | 2 | | 39-R17 | 2 | | 39-R32 | 2 |
| 39-R03 | 2 | | 39-R18 | 2 | | 39-R33 | 2 |
| 39-R04 | 2 | | 39-R19 | 2 | | 39-R34 | 2 |
| 39-R05 | 3 | | 39-R20 | 2 | | 39-R35 | 2 |
| 39-R06 | 2 | | 39-R21 | 2 | | 39-R36 | 2 |
| 39-R07 | 2 | | 39-R22 | 2 | | 39-R37 | 2 |
| 39-R08 | 2 | | 39-R23 | 2 | | 39-R38 | 3 |
| 39-R09 | 2 | | 39-R24 | 2 | | 39-R39 | 2 |
| 39-R10 | 2 | | 39-R25 | 2 | | 39-R40 | 2 |
| 39-R11 | 2 | | 39-R26 | 3 | | 39-R41 | 2 |
| 39-R12 | 3 | | 39-R27 | 2 | | 39-R42 | 2 |
| 39-R13 | 3 | | 39-R28 | 3 | | 39-R43 | 3 |
| 39-R14 | 2 | | 39-R29 | 3 | | | |
| 39-R15 | 2 | | 39-R30 | 2 | | | |

*Source:* HDR, Inc.

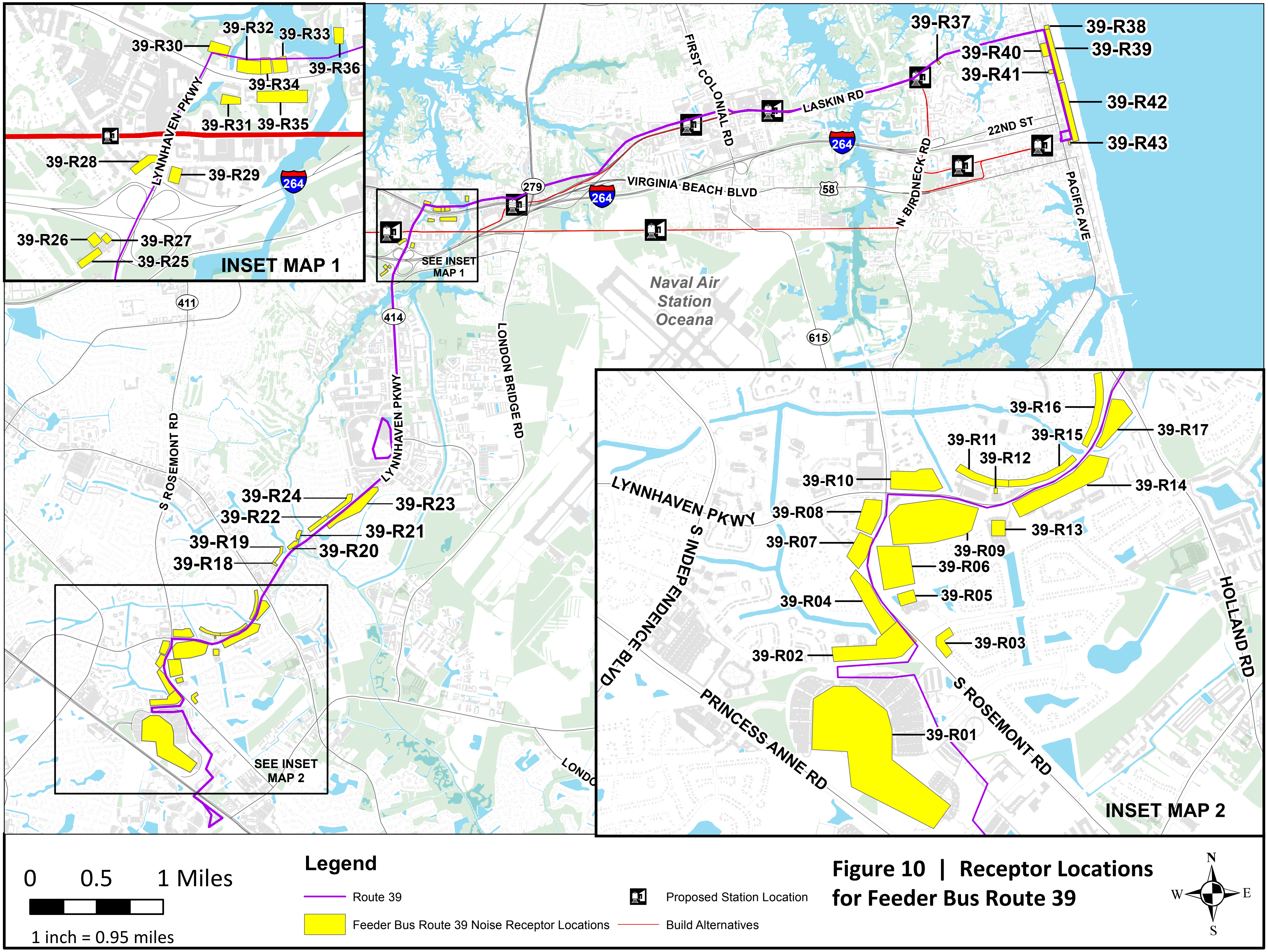



**Figure 10 | Receptor Locations for Feeder Bus Route 39**

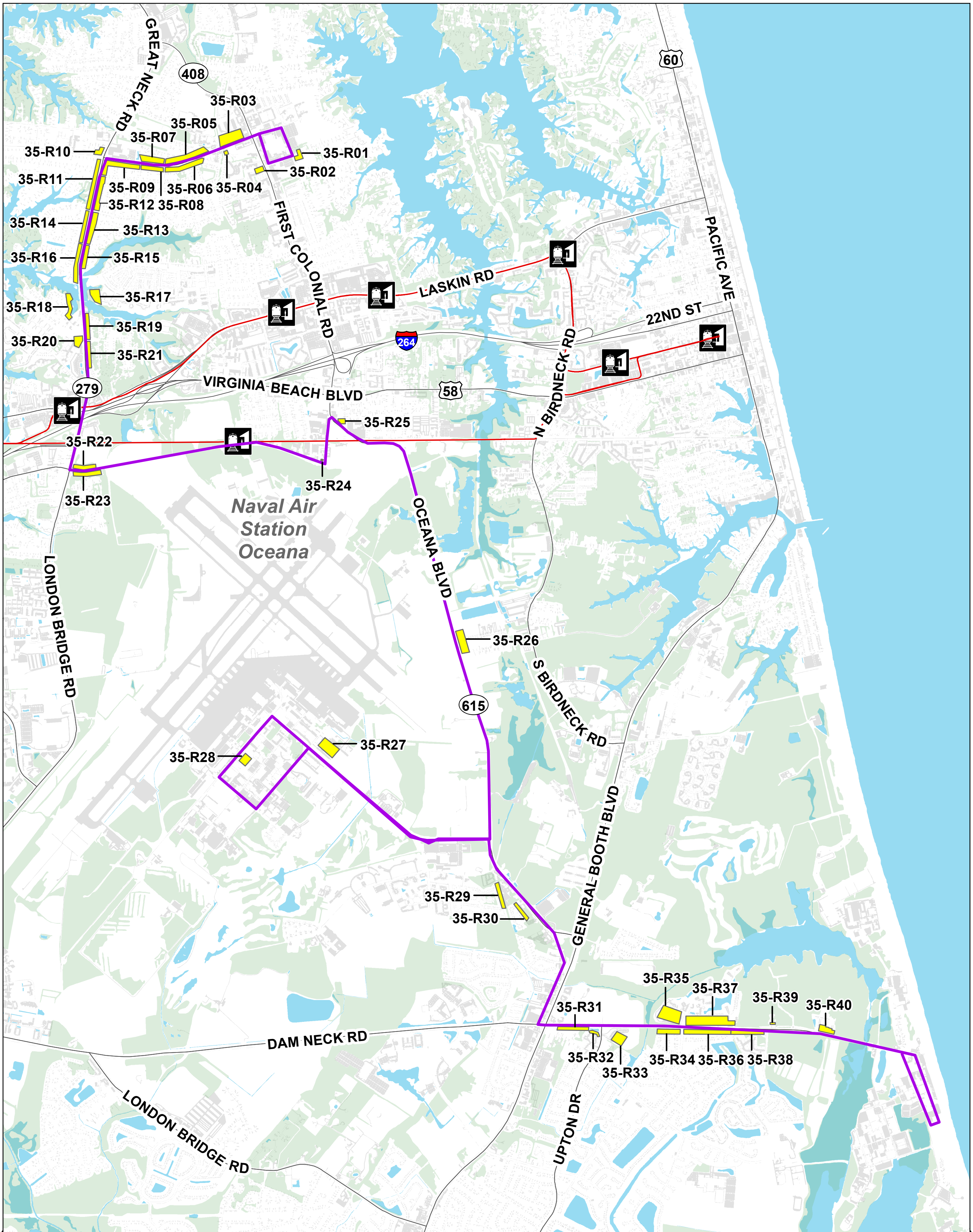
**Table 5** lists the noise-sensitive receptors identified along feeder bus Route 35. **Figure 11** shows the locations of these receptors.

**Table 5 | Noise-Sensitive Receptors for Feeder Bus Route 35**

| Receptor | Land Use Category | Receptor | Land Use Category | Receptor | Land Use Category |
|---|---|---|---|---|---|
| 35-R01 | 2 | 35-R15 | 2 | 35-R29 | 2 |
| 35-R02 | 2 | 35-R16 | 2 | 35-R30 | 2 |
| 35-R03 | 2 | 35-R17 | 2 | 35-R31 | 2 |
| 35-R04 | 3 | 35-R18 | 2 | 35-R32 | 2 |
| 35-R05 | 2 | 35-R19 | 2 | 35-R33 | 3 |
| 35-R06 | 2 | 35-R20 | 2 | 35-R34 | 2 |
| 35-R07 | 2 | 35-R21 | 2 | 35-R35 | 2 |
| 35-R08 | 2 | 35-R22 | 2 | 35-R36 | 2 |
| 35-R09 | 2 | 35-R23 | 2 | 35-R37 | 2 |
| 35-R10 | 2 | 35-R24 | 2 | 35-R38 | 2 |
| 35-R11 | 2 | 35-R25 | 2 | 35-R39 | 2 |
| 35-R12 | 2 | 35-R26 | 2 | 35-R40 | 2 |
| 35-R13 | 2 | 35-R27 | 3 | | |
| 35-R14 | 2 | 35-R28 | 3 | | |

*Source:* HDR, Inc.

A majority of the noise-sensitive receptors were residential, but many institutional land uses and four recording studios (R10a, R10b, R10d, and 38-R57) were identified.




**Legend**

- Route 35
- Feeder Bus Route 35 Noise Receptor Locations
- Proposed Station Location
- Build Alternatives

**Figure 11 | Receptor Locations for Feeder Bus Route 35**

### 2.1.2 Measurement of Existing Noise Conditions

For this study, noise-sensitive receptors identified above were grouped into receptor clusters per FTA guidance. A receptor cluster is a group of receptors located in close proximity to each other and the proposed alignment; the outdoor noise environment is assumed to be the same throughout the cluster. Existing noise levels were then measured at locations along the LRT/BRT alignments to offer accurate representation of the receptor clusters. The proposed feeder bus routes were identified after the measurements were completed. AICUZ mapping for Oceana Naval Air Station was used to determine the existing noise exposures for a majority of the receptors along feeder bus routes 39 and 35 because aviation noise dominates the soundscape in these areas. The existing noise exposure estimation method of Section 5.4 of the FTA manual was used for all other receptors (along feeder bus route 38 and a few receptors not within the AICUZ mapping area).

HDR measured existing noise levels at 13 locations along the former NSRR right-of-way and the Alternative 2 alignment east of Birdneck Road in July 2009, providing representation for noise-sensitive receptors. Four 1-hour measurements were performed at each location, with an hour for each of the peak morning, midday, peak evening, and nighttime conditions. **Table 6** describes the instrument used to perform these measurements.

**Table 6 | Monitoring Equipment for Former NSRR ROW and Alternative 2 East of Birdneck Rd.**

| Analyzer | Microphone | Preamp | Date of Last Calibration |
|---|---|---|---|
| LD 820 (SN 1413) | LD 2541 (SN 7546) | LD PRM828 (SN 2158) | 7/13/2009 |

*Source:* HDR, Inc.

The calculated $L_{dn}$'s from these short-term measurements ranged from 61 to 76 dBA. According to American National Standards Institute (ANSI) S12.9 Part 3 (reaffirmed in 2008), an $L_{dn}$ of 60 dBA is typical for an urban or noisy suburban residential environment and 70 dBA is typical for a very noisy urban environment.

Alternative 3 was added to the project in 2012. In September 2013, HDR measured existing noise levels for a continuous 24-hour period at six additional locations that are associated with this alignment outside of the former NSRR ROW. The locations were determined to be representative of their surroundings based on a review of aerial photographs and a windshield survey of the study area. **Table 7** describes the instruments used to perform these measurements.

**Table 7 | Monitoring Equipment for Alternative 3 outside of Former NSRR ROW**

| Analyzer | Microphone | Preamp | Date of Last Calibration |
|---|---|---|---|
| LD 824 (SN3204) | PCB Piezotronics 377B41 (SN 1004) | LD PRM902 (SN 3380) | 6/22/2011 |
| LD 824 (SN 2636) | LD 2541 (SN 7490) | LD PRM902 (SN 2618) | 5/10/2012 |
| LD 824 (SN 0764) | LD 2541 (SN 4185) | LD PRM902 (SN 1207) | 5/1/2013 |

*Source:* HDR, Inc.

**Table 8** presents the dates and times of the measurements taken along the Alternative 3 alignment outside of the former NSRR ROW.

**Table 8 | Alternative 3 Monitoring Periods**

| Measurement Location | Start (date/time) | End (date/time) |
|---|---|---|
| M14 | 9/18/2013 11:44 AM | 9/19/2013 12:08 PM |
| M15 | 9/18/2013 10:45 AM | 9/19/2013 11:09 AM |
| M16 | 9/17/2013 9:00 AM | 9/18/2013 9:13 AM |
| M17 | 9/18/2013 9:39 AM | 9/19/2013 10:52 AM |
| M18 | 9/17/2013 10:14 AM | 9/18/2013 11:14 AM |
| M19 | 9/17/2013 9:43 AM | 9/18/2013 10:12 AM |

*Source:* HDR, Inc.

The measured $L_{dn}$'s from these 24-hour monitoring locations ranged from 69 to 77 dBA. According to ANSI S12.9 Part 3, this range of values is typical for a very noisy urban environment.

The existing noise exposure estimation method from Section 5.4 of the FTA manual is based upon distances from major noise sources and population densities. Table 5-7 of the FTA manual provides individual noise exposure levels based upon the distance from interstate highways, distance from other major roadways, distance from railroad lines, and population density. The maximum noise exposure from the four methods is then used as the existing noise exposure level for the receptor. The distances were measured using aerial photos, and the population densities were identified by census tract.

## 2.2 Predictions of Project-Related Noise

HDR used the FTA noise impact assessment spreadsheet model (FTA 2006) to evaluate project-related noise for both the LRT and BRT options on each alternative alignment. The spreadsheet model was applied directly, without modification. For the simpler feeder bus routes, equations from the FTA manual were used to calculate the moderate and severe impact thresholds, calculate the project-related noise levels, and determine if impacts occurred.

### 2.2.1 LRT Alternatives

The FTA spreadsheet model noise sources used for the LRT option included the following:

- Fixed Guideway – Rail Transit Vehicle
- Fixed Guideway – Transit Warning Device
- Stationary Source – Crossing Signals
- Stationary Source – Crossovers
- Stationary Source – Rail Yard and Shops (for the Vehicle Storage and Maintenance Facility)
- Stationary Source – Bus Storage Yard (for feeder bus idling at stations)
- Highway/Transit – Buses, Hybrid (for proposed feeder bus routes)

**Table 9** provides the LRT and BRT service frequencies used to calculate the daytime and nighttime events per hour. In all tables, daytime events are from 7:00 a.m. to 10:00 p.m., while nighttime events are from 10:00 p.m. to 7:00 a.m.

**Table 9 | Events per Hour for LRT and BRT Service**

| Time Period | Service Frequency, minutes | Number of Events |
|---|---|---|
| 6:00 am – 6:30 am | 15 | 2 |
| 6:30 am – 9:00 am | 10 | 15 |
| 9:00 am – 3:30 pm | 15 | 26 |
| 3:30 pm – 7:00 pm | 10 | 21 |
| 7:00 pm – 10:00 pm | 15 | 12 |
| 10:00 pm – midnight (Friday) | 30 | 4 |
| **Total Events per Day per Direction** | | **80** |
| **Total Events per Day Both Directions** | | **160** |
| **Daytime Events per Hour per Direction** | | **4.73** |
| **Daytime Events per Hour Both Directions** | | **9.47** |
| **Nighttime Events per Hour per Direction** | | **1.00** |
| **Nighttime Events per Hour Both Directions** | | **2.00** |

*Source:* HDR, Inc.

LRT vehicles will travel in both directions, so the daytime and nighttime events per hour in both directions were used. Noise from the Transit Warning Device was included in the FTA spreadsheet model if the receptor was adjacent to the 10 second approach distance from an at-grade crossing, as indicated by HRT operations staff. Because a receptor on one side of the crossing will hear trains from both directions, pass-by events in both directions were used for receptors adjacent to at-grade crossings. If a receptor was between two nearby crossings and within the 10 second approach distance of both, the daytime and nighttime events per hour both directions were doubled. The Crossing Signal duration was approximated as 30 seconds per crossing event based on a 20 second advance and calculated clearance time for the transit vehicle. HDR made a reasonable worst case assumption that LRT vehicles traveling opposite directions did not pass through a crossing at the same time – therefore a noise event was counted for each LRT vehicle moving through each crossing. Accordingly, the 30 seconds of Crossing Signal noise was multiplied by the daytime and nighttime events per hour both directions. This resulted in durations of 284 and 60 seconds per hour for the daytime and nighttime Crossing Signal noise exposures, respectively. LRT vehicles approach the crossovers from both directions, so the doubled daytime and nighttime events per hour both directions were again used.

A majority of the at-grade crossings would be gated. A stationary gate bell is used at these crossings, and the vehicle horn is applied two to three times beginning at the 10 second approach distance. Non-gated crossings are used for the Alternative 2 and Alternative 3 alignments from Birdneck Road to the eastern terminus on 19th Street at the Oceanfront station. Only a vehicle bell is used at non-gated crossings, as no stationary audible warning systems are present. Both the vehicle horn and vehicle bell are classified as Fixed Guideway – Transit Warning Device on the FTA noise impact assessment spreadsheet.

**Table 10** provides the number of vehicles departing from and returning to the Vehicle Storage and Maintenance Facility (VSMF), which was used to calculate the daytime and nighttime events per hour.

**Table 10 | Events per Hour for the VSMF**

| Time Period | Number of Events | |
|---|---|---|
| | LRT | BRT |
| 4:45 am – 6:00 am Departure | 8 | 5 |
| 5:45 am – 6:25 am Departure | 4 | 2 |
| 2:45 pm – 3:25 pm Departure | 4 | 2 |
| 9:15 am – 9:55 am Return | 4 | 2 |
| 7:15 pm – 7:55 pm Return | 4 | 2 |
| 10:15 pm – 10:55 pm Return | 4 | 2 |
| 12:15 am – 12:55 am Return | 4 | 3 |
| **Total Events per Day** | **32** | **18** |
| **Daytime Events per Hour** | **0.80** | **0.40** |
| **Nighttime Events per Hour** | **2.22** | **1.33** |

*Source:* HDR, Inc.

The number of VSMF events per hour was used at receptors near the VSMF. Additionally, the Hilltop alignment requires a section of access track along the former NSRR ROW to reach the VSMF. The number of VSMF events per hour for the Rail Transit Vehicle source for Alternative 3 was used to evaluate noise at receptors along the access track.

**Table 11** provides the feeder bus service frequencies used to calculate the daytime and nighttime events per hour.

**Table 11 | Events per Hour for the Feeder Buses**

| Time Period | Service Frequency, minutes | Number of Events |
|---|---|---|
| 6:00 am – 7:00 am | 30 | 2 |
| 7:00 am – 10:00 pm | 30 | 30 |
| 10:00 pm – midnight (Friday) | 30 | 4 |
| **Total Events per Day** | | **36** |
| **Daytime Events per Hour** | | **2.00** |
| **Nighttime Events per Hour** | | **0.67** |

*Source:* HDR, Inc.

For the LRT analysis, feeder buses idling at stations were modeled using the Stationary Source – Bus Storage Yard source. While not technically a Bus Storage Yard, this source has the same $SEL_{ref}$ as the Buses Idling source from the FTA's detailed noise assessment. The stations where feeder bus idling was included are as follows:

- Town Center (Alternatives 1A, 1B, 2, and 3)
- Rosemont (Alternatives 1B, 2, and 3)
- Hilltop West (Alternative 3)
- Hilltop East (Alternative 3)

Feeder bus noise at receptors near the proposed feeder bus alignments was modeled using the Highway Transit – Buses (Hybrid) source. The Buses (Hybrid) source was selected because it is the loudest bus source, and therefore it would provide the most conservative results.

### 2.2.2 BRT Alternatives

The analysis of noise from the BRT option included the following noise sources:

- Highway/Transit – Buses (Hybrid)
- Stationary Source – Bus Storage Yard

Under the BRT alternatives, no audible warnings will be used for at-grade crossings, and there are no additional sources with a paved road. The exact BRT vehicle had not been selected, so the most conservative Highway/Transit – Buses (Hybrid) was used. The Buses (Hybrid) source was used to account for BRT vehicles on the LRT/BRT alignment and feeder buses on the proposed feeder bus routes. Table 9 shows the BRT events per hour during both the daytime and nighttime in both directions. Table 11 shows the feeder buses events per hour in both the daytime and nighttime. The Bus Storage Yard source was used to account for the VSMF, BRT idling at all stations, and feeder bus idling at the same stations identified for the LRT analysis. The BRT idling, VSMF, and feeder bus idling used the service frequencies shown in **Table 9, Table 10, and Table 11**, respectively.

### 2.2.3 Feeder Bus Routes

Feeder bus noise was modeled using the Highway/Transit – Buses (Hybrid) as the noise source. A maximum speed of 35 mph was assumed for all proposed feeder bus routes. Equations given in Table 5-4 of the FTA manual were used to calculate the project-related levels at 50 feet. The levels were adjusted for distance and building shielding, where applicable, as discussed in Section 5.3 of the FTA manual.

## 3.0 Noise Impact Assessment

Using the stated FTA criteria, measured existing noise levels, and project-related noise estimates, the alignments and modes were assessed for noise impacts.

### 3.1 LRT Noise Analysis

**Table 12** contains the noise assessment results for the LRT mode for Alternative 1A.

**Table 12 | LRT Noise Assessment Results – Alternative 1A**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 57 | None |
| R2 | 2 | 61 | 58 | 63 | 56 | None |
| R3 | 3 | 53 | 59 | 65 | 50 | None |
| R4 | 2 | 61 | 58 | 63 | 56 | None |
| R5 | 2 | 61 | 58 | 63 | 51 | None |
| R5a | 3 | 61 | 63 | 68 | 55 | None |
| R6 | 2 | 61 | 58 | 63 | 61 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 59 | None |
| R8 | 2 | 62 | 59 | 64 | 69 | Severe |
| R9 | 3 | 55 | 60 | 66 | 67 | Severe |
| R10a | 1 | 60 | 58 | 63 | 57 | None |
| R10b | 1 | 55 | 55 | 61 | 49 | None |
| R10c | 3 | 55 | 60 | 66 | 49 | None |
| R10d | 1 | 55 | 55 | 61 | 49 | None |
| R11 | 2 | 62 | 59 | 64 | 66 | Severe |
| R12 | 2 | 62 | 59 | 64 | 66 | Severe |
| R13 | 3 | 64 | 65 | 70 | 69 | Moderate |
| R14 | 2 | 64 | 60 | 65 | 66 | Severe |

*Source:* HDR, Inc.

Analysis results indicate potential moderate and severe noise impacts under the LRT option for the Alternative 1A alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

**Table 13** contains the noise assessment results for the LRT option for the Alternative 1B alignment.

**Table 13 | LRT Noise Assessment Results – Alternative 1B**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 57 | None |
| R2 | 2 | 61 | 58 | 63 | 56 | None |
| R3 | 3 | 53 | 59 | 65 | 50 | None |
| R4 | 2 | 61 | 58 | 63 | 56 | None |
| R5 | 2 | 61 | 58 | 63 | 51 | None |
| R5a | 3 | 61 | 63 | 68 | 55 | None |
| R6 | 2 | 61 | 58 | 63 | 61 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 59 | None |
| R8 | 2 | 62 | 59 | 64 | 69 | Severe |
| R9 | 3 | 55 | 60 | 66 | 67 | Severe |
| R10a | 1 | 60 | 58 | 63 | 57 | None |
| R10b | 1 | 55 | 55 | 61 | 49 | None |
| R10c | 3 | 55 | 60 | 66 | 49 | None |
| R10d | 1 | 55 | 55 | 61 | 49 | None |
| R11 | 2 | 62 | 59 | 64 | 66 | Severe |
| R12 | 2 | 62 | 59 | 64 | 66 | Severe |
| R13 | 3 | 64 | 65 | 70 | 69 | Moderate |
| R14 | 2 | 64 | 60 | 65 | 66 | Severe |
| R15 | 2 | 64 | 60 | 65 | 67 | Severe |
| R16 | 2 | 64 | 60 | 65 | 54 | None |
| R17a | 2 | 61 | 58 | 64 | 56 | None |
| R17b | 2 | 61 | 58 | 64 | 71 | Severe |
| R18 | 2 | 61 | 58 | 64 | 67 | Severe |
| R19 | 2 | 61 | 58 | 64 | 55 | None |
| R20 | 2 | 61 | 58 | 64 | 52 | None |
| R21 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R22 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R23 | 3 | 71 | 70 | 75 | 48 | None |
| R24 | 2 | 70 | 64 | 69 | 53 | None |

*Source:* HDR, Inc.

Analysis results indicate potential moderate and severe noise impacts under the LRT option for the Alternative 1B alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

**Table 14** contains the noise assessment results for the LRT option for the Alternative 2 alignment.

**Table 14 | LRT Noise Assessment Results – Alternative 2**

| Receptor | Land Use Category | Existing Level ($L_{dn}$/$L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}$/$L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}$/$L_{eq}$ dBA) | Project Level ($L_{dn}$/$L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 57 | None |
| R2 | 2 | 61 | 58 | 63 | 56 | None |
| R3 | 3 | 53 | 59 | 65 | 50 | None |
| R4 | 2 | 61 | 58 | 63 | 56 | None |
| R5 | 2 | 61 | 58 | 63 | 51 | None |
| R5a | 3 | 61 | 63 | 68 | 55 | None |
| R6 | 2 | 61 | 58 | 63 | 61 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 59 | None |
| R8 | 2 | 62 | 59 | 64 | 69 | Severe |
| R9 | 3 | 55 | 60 | 66 | 67 | Severe |
| R10a | 1 | 60 | 58 | 63 | 57 | None |
| R10b | 1 | 55 | 55 | 61 | 49 | None |
| R10c | 3 | 55 | 60 | 66 | 49 | None |
| R10d | 1 | 55 | 55 | 61 | 49 | None |
| R11 | 2 | 62 | 59 | 64 | 66 | Severe |
| R12 | 2 | 62 | 59 | 64 | 66 | Severe |
| R13 | 3 | 64 | 65 | 70 | 69 | Moderate |
| R14 | 2 | 64 | 60 | 65 | 66 | Severe |
| R15 | 2 | 64 | 60 | 65 | 67 | Severe |
| R16 | 2 | 64 | 60 | 65 | 54 | None |
| R17a | 2 | 61 | 58 | 64 | 56 | None |
| R17b | 2 | 61 | 58 | 64 | 71 | Severe |
| R18 | 2 | 61 | 58 | 64 | 67 | Severe |
| R19 | 2 | 61 | 58 | 64 | 55 | None |
| R20 | 2 | 61 | 58 | 64 | 52 | None |
| R21 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R22 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R23 | 3 | 71 | 70 | 75 | 48 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| R24 | 2 | 70 | 64 | 69 | 53 | None |
| R25 | 2 | 67 | 61 | 67 | 59 | None |
| R26 | 2 | 70 | 64 | 69 | 53 | None |
| R27 | 2 | 70 | 64 | 69 | 72 | Severe |
| R28 | 3 | 76 | 70 | 78 | 71 | Moderate |
| R29 | 2 | 70 | 64 | 69 | 56 | None |
| R30 | 3 | 76 | 70 | 78 | 55 | None |
| R31 | 2 | 70 | 64 | 69 | 57 | None |
| R32 | 3 | 52 | 59 | 65 | 44 | None |
| R33 | 2 | 72 | 65 | 71 | 66 | Moderate |
| R34 | 3 | 79 | 70 | 80 | 52 | None |
| R35a | 2 | 76 | 65 | 73 | 70 | Moderate |
| R35b | 2 | 76 | 65 | 73 | 55 | None |
| R36 | 2 | 76 | 65 | 73 | 56 | None |
| R37 | 3 | 75 | 70 | 78 | 51 | None |
| R38 | 2 | 76 | 65 | 73 | 70 | Moderate |
| R39 | 2 | 76 | 65 | 73 | 66 | Moderate |
| R40 | 2 | 71 | 65 | 70 | 70 | Moderate |
| R41 | 2 | 71 | 65 | 70 | 73 | Severe |
| R42 | 2 | 71 | 65 | 70 | 69 | Moderate |
| R43 | 2 | 71 | 65 | 70 | 73 | Severe |
| R44 | 2 | 71 | 65 | 70 | 50 | None |
| R45 | 3 | 61 | 63 | 69 | 59 | None |
| R46 | 2 | 69 | 64 | 69 | 52 | None |
| R47 | 2 | 69 | 64 | 69 | 63 | None |
| R48 | 2 | 66 | 61 | 66 | 68 | Severe |
| R49 | 2 | 66 | 61 | 66 | 76 | Severe |
| R50 | 2 | 66 | 61 | 66 | 75 | Severe |
| R51 | 2 | 66 | 61 | 66 | 70 | Severe |
| R52 | 2 | 66 | 61 | 66 | 74 | Severe |
| R53 | 2 | 66 | 61 | 66 | 73 | Severe |
| R54 | 2 | 66 | 61 | 66 | 76 | Severe |
| R56 | 2 | 66 | 61 | 66 | 75 | Severe |

*Source:* HDR, Inc.

Analysis results indicate potential for both moderate and severe noise impacts for the LRT option for the Alternative 2 alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

**Table 15** contains the noise assessment results for the LRT option for the Alternative 3 alignment.

**Table 15 | LRT Noise Assessment Results – Alternative 3**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 57 | None |
| R2 | 2 | 61 | 58 | 63 | 56 | None |
| R3 | 3 | 53 | 59 | 65 | 50 | None |
| R4 | 2 | 61 | 58 | 63 | 56 | None |
| R5 | 2 | 61 | 58 | 63 | 51 | None |
| R5a | 3 | 61 | 63 | 68 | 55 | None |
| R6 | 2 | 61 | 58 | 63 | 61 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 59 | None |
| R8 | 2 | 62 | 59 | 64 | 69 | Severe |
| R9 | 3 | 55 | 60 | 66 | 67 | Severe |
| R10a | 1 | 60 | 58 | 63 | 57 | None |
| R10b | 1 | 55 | 55 | 61 | 49 | None |
| R10c | 3 | 55 | 60 | 66 | 49 | None |
| R10d | 1 | 55 | 55 | 61 | 49 | None |
| R11 | 2 | 62 | 59 | 64 | 66 | Severe |
| R12 | 2 | 62 | 59 | 64 | 66 | Severe |
| R13 | 3 | 64 | 65 | 70 | 69 | Moderate |
| R14 | 2 | 64 | 60 | 65 | 66 | Severe |
| R15 | 2 | 64 | 60 | 65 | 67 | Severe |
| R16 | 2 | 64 | 60 | 65 | 54 | None |
| R17a | 2 | 61 | 58 | 64 | 56 | None |
| R17b | 2 | 61 | 58 | 64 | 71 | Severe |
| R18 | 2 | 61 | 58 | 64 | 67 | Severe |
| R19 | 2 | 61 | 58 | 64 | 55 | None |
| R20 | 2 | 61 | 58 | 64 | 52 | None |
| R21 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R22 | 2 | 61 | 58 | 64 | 59 | Moderate |
| R23 | 3 | 71 | 70 | 75 | 48 | None |
| R24 | 2 | 70 | 64 | 69 | 53 | None |
| R25 | 2 | 67 | 61 | 67 | 59 | None |
| R26 | 2 | 70 | 64 | 69 | 53 | None |
| R27 | 2 | 70 | 64 | 69 | 72 | Severe |
| R28 | 3 | 76 | 70 | 78 | 71 | Moderate |

| | | | | | | |
|---|---|---|---|---|---|---|
| R29 | 2 | 70 | 64 | 69 | 56 | None |
| R30 | 3 | 76 | 70 | 78 | 55 | None |
| R31 | 2 | 70 | 64 | 69 | 57 | None |
| R32 | 3 | 52 | 59 | 65 | 33 | None |
| R33 | 2 | 72 | 65 | 71 | 64 | None |
| R34 | 3 | 79 | 70 | 80 | 42 | None |
| R35b | 2 | 76 | 65 | 73 | 55 | None |
| R48 | 2 | 66 | 61 | 66 | 68 | Severe |
| R49 | 2 | 66 | 61 | 66 | 76 | Severe |
| R50 | 2 | 66 | 61 | 66 | 75 | Severe |
| R51 | 2 | 66 | 61 | 66 | 70 | Severe |
| R52 | 2 | 66 | 61 | 66 | 74 | Severe |
| R53 | 2 | 66 | 61 | 66 | 73 | Severe |
| R54 | 2 | 66 | 61 | 66 | 76 | Severe |
| R56 | 2 | 66 | 61 | 66 | 75 | Severe |
| R58 | 2 | 74 | 65 | 72 | 61 | None |
| R59 | 2 | 69 | 64 | 69 | 56 | None |
| R60 | 2 | 69 | 64 | 69 | 62 | None |
| R61 | 2 | 73 | 65 | 72 | 56 | None |
| R62 | 2 | 77 | 65 | 75 | 71 | Moderate |
| R63 | 2 | 77 | 65 | 75 | 51 | None |

*Source:* HDR, Inc.

Analysis results indicate potential moderate and severe noise impacts under the LRT option for the Alternative 3 alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

## 3.2 BRT Noise Analysis

**Table 16** contains the noise assessment results for the BRT option for the Alternative 1A alignment.

**Table 16 | BRT Noise Assessment Results – Alternative 1A**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 55 | None |
| R2 | 2 | 61 | 58 | 63 | 54 | None |
| R3 | 3 | 53 | 59 | 65 | 48 | None |
| R4 | 2 | 61 | 58 | 63 | 54 | None |
| R5 | 2 | 61 | 58 | 63 | 49 | None |
| R5a | 3 | 61 | 63 | 68 | 53 | None |
| R6 | 2 | 61 | 58 | 63 | 59 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 57 | None |
| R8 | 2 | 62 | 59 | 64 | 57 | None |
| R9 | 3 | 55 | 60 | 66 | 55 | None |
| R10a | 1 | 60 | 58 | 63 | 45 | None |
| R10b | 1 | 55 | 55 | 61 | 47 | None |
| R10c | 3 | 55 | 60 | 66 | 47 | None |
| R10d | 1 | 55 | 55 | 61 | 47 | None |
| R11 | 2 | 62 | 59 | 64 | 54 | None |
| R12 | 2 | 62 | 59 | 64 | 54 | None |
| R13 | 3 | 64 | 65 | 70 | 56 | None |
| R14 | 2 | 64 | 60 | 65 | 52 | None |

*Source:* HDR, Inc.

Analysis results indicate potential for a single moderate noise impact for the BRT option for the Alternative 1A alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

**Table 17** contains the noise assessment results for the BRT option for the Alternative 1B alignment.

**Table 17 | BRT Noise Assessment Results – Alternative 1B**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 55 | None |
| R2 | 2 | 61 | 58 | 63 | 54 | None |
| R3 | 3 | 53 | 59 | 65 | 48 | None |
| R4 | 2 | 61 | 58 | 63 | 54 | None |
| R5 | 2 | 61 | 58 | 63 | 49 | None |
| R5a | 3 | 61 | 63 | 68 | 53 | None |
| R6 | 2 | 61 | 58 | 63 | 59 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 57 | None |
| R8 | 2 | 62 | 59 | 64 | 57 | None |
| R9 | 3 | 55 | 60 | 66 | 55 | None |
| R10a | 1 | 60 | 58 | 63 | 45 | None |
| R10b | 1 | 55 | 55 | 61 | 47 | None |
| R10c | 3 | 55 | 60 | 66 | 47 | None |
| R10d | 1 | 55 | 55 | 61 | 47 | None |
| R11 | 2 | 62 | 59 | 64 | 54 | None |
| R12 | 2 | 62 | 59 | 64 | 54 | None |
| R13 | 3 | 64 | 65 | 70 | 56 | None |
| R14 | 2 | 64 | 60 | 65 | 52 | None |
| R15 | 2 | 64 | 60 | 65 | 54 | None |
| R16 | 2 | 64 | 60 | 65 | 52 | None |
| R17a | 2 | 61 | 58 | 64 | 54 | None |
| R17b | 2 | 61 | 58 | 64 | 57 | None |
| R18 | 2 | 61 | 58 | 64 | 54 | None |
| R19 | 2 | 61 | 58 | 64 | 53 | None |
| R20 | 2 | 61 | 58 | 64 | 50 | None |
| R21 | 2 | 61 | 58 | 64 | 57 | None |
| R22 | 2 | 61 | 58 | 64 | 57 | None |
| R23 | 3 | 71 | 70 | 75 | 46 | None |
| R24 | 2 | 70 | 64 | 69 | 58 | None |

*Source:* HDR, Inc.

Analysis results indicate potential for a single moderate noise impact for the BRT option for the Alternative 1B alignment. The contribution of the individual sources is discussed in the Noise Mitigation section.

**Table 18** contains the noise assessment results for the BRT option for the Alternative 2 alignment.

**Table 18 | BRT Noise Assessment Results – Alternative 2**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 55 | None |
| R2 | 2 | 61 | 58 | 63 | 54 | None |
| R3 | 3 | 53 | 59 | 65 | 48 | None |
| R4 | 2 | 61 | 58 | 63 | 54 | None |
| R5 | 2 | 61 | 58 | 63 | 49 | None |
| R5a | 3 | 61 | 63 | 68 | 53 | None |
| R6 | 2 | 61 | 58 | 63 | 59 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 57 | None |
| R8 | 2 | 62 | 59 | 64 | 57 | None |
| R9 | 3 | 55 | 60 | 66 | 55 | None |
| R10a | 1 | 60 | 58 | 63 | 45 | None |
| R10b | 1 | 55 | 55 | 61 | 47 | None |
| R10c | 3 | 55 | 60 | 66 | 47 | None |
| R10d | 1 | 55 | 55 | 61 | 47 | None |
| R11 | 2 | 62 | 59 | 64 | 54 | None |
| R12 | 2 | 62 | 59 | 64 | 54 | None |
| R13 | 3 | 64 | 65 | 70 | 56 | None |
| R14 | 2 | 64 | 60 | 65 | 52 | None |
| R15 | 2 | 64 | 60 | 65 | 54 | None |
| R16 | 2 | 64 | 60 | 65 | 52 | None |
| R17a | 2 | 61 | 58 | 64 | 54 | None |
| R17b | 2 | 61 | 58 | 64 | 57 | None |
| R18 | 2 | 61 | 58 | 64 | 54 | None |
| R19 | 2 | 61 | 58 | 64 | 53 | None |
| R20 | 2 | 61 | 58 | 64 | 50 | None |
| R21 | 2 | 61 | 58 | 64 | 57 | None |
| R22 | 2 | 61 | 58 | 64 | 57 | None |
| R23 | 3 | 71 | 70 | 75 | 46 | None |
| R24 | 2 | 70 | 64 | 69 | 58 | None |
| R25 | 2 | 67 | 61 | 67 | 57 | None |
| R26 | 2 | 70 | 64 | 69 | 51 | None |
| R27 | 2 | 70 | 64 | 69 | 58 | None |
| R28 | 3 | 76 | 70 | 78 | 58 | None |
| R29 | 2 | 70 | 64 | 69 | 54 | None |
| R30 | 3 | 76 | 70 | 78 | 53 | None |
| R31 | 2 | 70 | 64 | 69 | 51 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| R32 | 3 | 52 | 59 | 65 | 42 | None |
| R33 | 2 | 72 | 65 | 71 | 55 | None |
| R34 | 3 | 79 | 70 | 80 | 40 | None |
| R35a | 2 | 76 | 65 | 73 | 57 | None |
| R35b | 2 | 76 | 65 | 73 | 44 | None |
| R36 | 2 | 76 | 65 | 73 | 54 | None |
| R37 | 3 | 75 | 70 | 78 | 50 | None |
| R38 | 2 | 76 | 65 | 73 | 55 | None |
| R39 | 2 | 76 | 65 | 73 | 55 | None |
| R40 | 2 | 71 | 65 | 70 | 55 | None |
| R41 | 2 | 71 | 65 | 70 | 55 | None |
| R42 | 2 | 71 | 65 | 70 | 54 | None |
| R43 | 2 | 71 | 65 | 70 | 55 | None |
| R44 | 2 | 71 | 65 | 70 | 48 | None |
| R45 | 3 | 61 | 63 | 69 | 44 | None |
| R46 | 2 | 69 | 64 | 69 | 50 | None |
| R47 | 2 | 69 | 64 | 69 | 49 | None |
| R48 | 2 | 66 | 61 | 66 | 43 | None |
| R49 | 2 | 66 | 61 | 66 | 51 | None |
| R50 | 2 | 66 | 61 | 66 | 49 | None |
| R51 | 2 | 66 | 61 | 66 | 48 | None |
| R52 | 2 | 66 | 61 | 66 | 53 | None |
| R53 | 2 | 66 | 61 | 66 | 50 | None |
| R54 | 2 | 66 | 61 | 66 | 51 | None |
| R56 | 2 | 66 | 61 | 66 | 64 | Moderate |

*Source:* HDR, Inc.

Analysis results indicate potential for moderate noise impacts for the BRT option for the Alternative 2 alignment. The contribution of the individual sources is discussed in the Noise Mitigation section. The number of impacts is greatly reduced from the LRT option due to the absence of audible warning systems. The moderate impact at R6 is solely the result of wayside BRT vehicle noise, and the moderate impact at R56 is due to BRT idling at the Oceanfront station.

**Table 19** contains the noise assessment results for the BRT option for the Alternative 3 alignment.

**Table 19 | BRT Noise Assessment Results – Alternative 3**

| Receptor | Land Use Category | Existing Level ($L_{dn}$/$L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}$/$L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}$/$L_{eq}$ dBA) | Project Level ($L_{dn}$/$L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| R1 | 2 | 61 | 58 | 63 | 55 | None |
| R2 | 2 | 61 | 58 | 63 | 54 | None |
| R3 | 3 | 53 | 59 | 65 | 48 | None |
| R4 | 2 | 61 | 58 | 63 | 54 | None |
| R5 | 2 | 61 | 58 | 63 | 49 | None |
| R5a | 3 | 61 | 63 | 68 | 53 | None |
| R6 | 2 | 61 | 58 | 63 | 59 | Moderate |
| R7 | 3 | 61 | 63 | 68 | 57 | None |
| R8 | 2 | 62 | 59 | 64 | 57 | None |
| R9 | 3 | 55 | 60 | 66 | 55 | None |
| R10a | 1 | 60 | 58 | 63 | 45 | None |
| R10b | 1 | 55 | 55 | 61 | 47 | None |
| R10c | 3 | 55 | 60 | 66 | 47 | None |
| R10d | 1 | 55 | 55 | 61 | 47 | None |
| R11 | 2 | 62 | 59 | 64 | 54 | None |
| R12 | 2 | 62 | 59 | 64 | 54 | None |
| R13 | 3 | 64 | 65 | 70 | 56 | None |
| R14 | 2 | 64 | 60 | 65 | 52 | None |
| R15 | 2 | 64 | 60 | 65 | 54 | None |
| R16 | 2 | 64 | 60 | 65 | 52 | None |
| R17a | 2 | 61 | 58 | 64 | 54 | None |
| R17b | 2 | 61 | 58 | 64 | 57 | None |
| R18 | 2 | 61 | 58 | 64 | 54 | None |
| R19 | 2 | 61 | 58 | 64 | 53 | None |
| R20 | 2 | 61 | 58 | 64 | 50 | None |
| R21 | 2 | 61 | 58 | 64 | 57 | None |
| R22 | 2 | 61 | 58 | 64 | 57 | None |
| R23 | 3 | 71 | 70 | 75 | 46 | None |
| R24 | 2 | 70 | 64 | 69 | 58 | None |
| R25 | 2 | 67 | 61 | 67 | 57 | None |
| R26 | 2 | 70 | 64 | 69 | 51 | None |
| R27 | 2 | 70 | 64 | 69 | 58 | None |
| R28 | 3 | 76 | 70 | 78 | 58 | None |
| R29 | 2 | 70 | 64 | 69 | 54 | None |
| R30 | 3 | 76 | 70 | 78 | 53 | None |
| R31 | 2 | 70 | 64 | 69 | 51 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| R32 | 3 | 52 | 59 | 65 | 28 | None |
| R33 | 2 | 72 | 65 | 71 | 52 | None |
| R34 | 3 | 79 | 70 | 80 | 27 | None |
| R35b | 2 | 76 | 65 | 73 | 44 | None |
| R48 | 2 | 66 | 61 | 66 | 43 | None |
| R49 | 2 | 66 | 61 | 66 | 51 | None |
| R50 | 2 | 66 | 61 | 66 | 49 | None |
| R51 | 2 | 66 | 61 | 66 | 48 | None |
| R52 | 2 | 66 | 61 | 66 | 53 | None |
| R53 | 2 | 66 | 61 | 66 | 50 | None |
| R54 | 2 | 66 | 61 | 66 | 51 | None |
| R56 | 2 | 66 | 61 | 66 | 64 | Moderate |
| R58 | 2 | 74 | 65 | 72 | 53 | None |
| R59 | 2 | 69 | 64 | 69 | 43 | None |
| R60 | 2 | 69 | 64 | 69 | 45 | None |
| R61 | 2 | 73 | 65 | 72 | 52 | None |
| R62 | 2 | 77 | 65 | 75 | 49 | None |
| R63 | 2 | 77 | 65 | 75 | 46 | None |

*Source:* HDR, Inc.

Analysis results indicate potential for moderate noise impacts for the BRT option for the Alternative 3 alignment similar to those identified for Alternative 2. The contribution of the individual sources is discussed in the Noise Mitigation section.

## 3.3 Feeder Bus Noise Analysis

Alternatives 2 and 3 include all three new feeder bus routes, while Alternatives 1A and 1B only includes Route 38 and Route 39. **Table 20** contains the noise assessment results for feeder bus Route 38.

**Table 20 | Feeder Bus Noise Assessment Results – Route 38**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| 38-R01 | 3 | 65 | 66 | 71 | 45 | None |
| 38-R02 | 2 | 55 | 55 | 61 | 40 | None |
| 38-R03 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R04 | 2 | 55 | 55 | 61 | 43 | None |
| 38-R05 | 2 | 60 | 58 | 63 | 47 | None |
| 38-R06 | 3 | 65 | 66 | 71 | 45 | None |
| 38-R07 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R08 | 3 | 55 | 60 | 66 | 36 | None |
| 38-R09 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R10 | 2 | 60 | 58 | 63 | 46 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| 38-R11 | 2 | 55 | 55 | 61 | 42 | None |
| 38-R12 | 2 | 55 | 55 | 61 | 43 | None |
| 38-R13 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R14 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R15 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R16 | 2 | 60 | 58 | 63 | 46 | None |
| 38-R17 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R18 | 2 | 55 | 55 | 61 | 44 | None |
| 38-R19 | 3 | 55 | 60 | 66 | 41 | None |
| 38-R20 | 2 | 55 | 55 | 61 | 44 | None |
| 38-R21 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R22 | 3 | 55 | 60 | 66 | 41 | None |
| 38-R23 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R24 | 3 | 65 | 66 | 71 | 45 | None |
| 38-R25 | 3 | 55 | 60 | 66 | 40 | None |
| 38-R26 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R27 | 2 | 60 | 58 | 63 | 42 | None |
| 38-R28 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R29 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R30 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R31 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R32 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R33 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R34 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R35 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R36 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R37 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R38 | 2 | 60 | 58 | 63 | 40 | None |
| 38-R39 | 2 | 60 | 58 | 63 | 45 | None |
| 38-R40 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R41 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R42 | 2 | 65 | 61 | 66 | 50 | None |
| 38-R43 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R44 | 2 | 55 | 55 | 61 | 38 | None |
| 38-R45 | 3 | 65 | 66 | 71 | 46 | None |
| 38-R46 | 2 | 65 | 61 | 66 | 38 | None |
| 38-R47 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R48 | 3 | 55 | 60 | 66 | 41 | None |
| 38-R49 | 2 | 65 | 61 | 66 | 49 | None |
| 38-R50 | 2 | 65 | 61 | 66 | 48 | None |
| 38-R51 | 3 | 60 | 63 | 68 | 44 | None |
| 38-R52 | 3 | 65 | 66 | 71 | 45 | None |
| 38-R53 | 3 | 55 | 60 | 66 | 41 | None |
| 38-R54 | 2 | 55 | 55 | 61 | 42 | None |
| 38-R55 | 3 | 60 | 63 | 68 | 39 | None |
| 38-R56 | 2 | 60 | 58 | 63 | 45 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| 38-R57 | 1 | 55 | 55 | 61 | 40 | None |
| 38-R58 | 2 | 60 | 58 | 63 | 46 | None |
| 38-R59 | 2 | 60 | 58 | 63 | 46 | None |
| 38-R60 | 2 | 55 | 55 | 61 | 44 | None |
| 38-R61 | 3 | 65 | 66 | 71 | 47 | None |

*Source:* HDR, Inc.

Analysis results indicate that noise impacts are not projected to occur under feeder bus Route 38. **Table 21** contains the noise assessment results for feeder bus Route 39.

**Table 21 | Feeder Bus Noise Assessment Results – Route 39**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| 39-R01 | 3 | 65 | 66 | 71 | 43 | None |
| 39-R02 | 2 | 70 | 64 | 69 | 52 | None |
| 39-R03 | 2 | 65 | 61 | 66 | 44 | None |
| 39-R04 | 2 | 70 | 64 | 69 | 52 | None |
| 39-R05 | 3 | 65 | 66 | 71 | 42 | None |
| 39-R06 | 2 | 65 | 61 | 66 | 47 | None |
| 39-R07 | 2 | 70 | 64 | 69 | 55 | None |
| 39-R08 | 2 | 65 | 61 | 66 | 49 | None |
| 39-R09 | 2 | 65 | 61 | 66 | 47 | None |
| 39-R10 | 2 | 65 | 61 | 66 | 49 | None |
| 39-R11 | 2 | 65 | 61 | 66 | 40 | None |
| 39-R12 | 3 | 65 | 66 | 71 | 43 | None |
| 39-R13 | 3 | 65 | 66 | 71 | 41 | None |
| 39-R14 | 2 | 65 | 61 | 66 | 49 | None |
| 39-R15 | 2 | 65 | 61 | 66 | 49 | None |
| 39-R16 | 2 | 70 | 64 | 69 | 50 | None |
| 39-R17 | 2 | 70 | 64 | 69 | 50 | None |
| 39-R18 | 2 | 70 | 64 | 69 | 47 | None |
| 39-R19 | 2 | 70 | 64 | 69 | 44 | None |
| 39-R20 | 2 | 75 | 65 | 73 | 52 | None |
| 39-R21 | 2 | 75 | 65 | 73 | 45 | None |
| 39-R22 | 2 | 75 | 65 | 73 | 46 | None |
| 39-R23 | 2 | 75 | 65 | 73 | 49 | None |
| 39-R24 | 2 | 75 | 65 | 73 | 48 | None |
| 39-R25 | 2 | 75 | 65 | 73 | 43 | None |
| 39-R26 | 3 | 75 | 70 | 78 | 40 | None |
| 39-R27 | 2 | 75 | 65 | 73 | 44 | None |
| 39-R28 | 3 | 75 | 70 | 78 | 45 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| 39-R29 | 3 | 75 | 70 | 78 | 43 | None |
| 39-R30 | 2 | 75 | 65 | 73 | 43 | None |
| 39-R31 | 2 | 75 | 65 | 73 | 39 | None |
| 39-R32 | 2 | 75 | 65 | 73 | 46 | None |
| 39-R33 | 2 | 75 | 65 | 73 | 48 | None |
| 39-R34 | 2 | 75 | 65 | 73 | 47 | None |
| 39-R35 | 2 | 75 | 65 | 73 | 46 | None |
| 39-R36 | 2 | 75 | 65 | 73 | 42 | None |
| 39-R37 | 2 | 70 | 64 | 69 | 49 | None |
| 39-R38 | 3 | 65 | 66 | 71 | 49 | None |
| 39-R39 | 2 | 65 | 61 | 66 | 55 | None |
| 39-R40 | 2 | 65 | 61 | 66 | 55 | None |
| 39-R41 | 2 | 65 | 61 | 66 | 55 | None |
| 39-R42 | 2 | 65 | 61 | 66 | 55 | None |
| 39-R43 | 3 | 65 | 66 | 71 | 49 | None |

*Source:* HDR, Inc.

Analysis results indicate that noise impacts are not projected to occur under feeder bus Route 39. **Table 22** contains the noise assessment results for feeder bus Route 35.

**Table 22 | Feeder Bus Noise Assessment Results – Route 35**

| Receptor | Land Use Category | Existing Level ($L_{dn}/L_{eq}$ dBA) | Moderate Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Severe Noise Impact Threshold ($L_{dn}/L_{eq}$ dBA) | Project Level ($L_{dn}/L_{eq}$ dBA) | Impact |
|---|---|---|---|---|---|---|
| 35-R01 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R02 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R03 | 2 | 70 | 64 | 69 | 51 | None |
| 35-R04 | 3 | 70 | 69 | 74 | 43 | None |
| 35-R05 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R06 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R07 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R08 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R09 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R10 | 2 | 65 | 61 | 66 | 46 | None |
| 35-R11 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R12 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R13 | 2 | 75 | 65 | 73 | 50 | None |
| 35-R14 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R15 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R16 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R17 | 2 | 75 | 65 | 73 | 43 | None |
| 35-R18 | 2 | 75 | 65 | 73 | 43 | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| 35-R19 | 2 | 75 | 65 | 73 | 48 | None |
| 35-R20 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R21 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R22 | 2 | 75 | 65 | 73 | 51 | None |
| 35-R23 | 2 | 75 | 65 | 73 | 51 | None |
| 35-R24 | 2 | 75 | 65 | 73 | 50 | None |
| 35-R25 | 2 | 75 | 65 | 73 | 47 | None |
| 35-R26 | 2 | 75 | 65 | 73 | 47 | None |
| 35-R27 | 3 | 75 | 70 | 78 | 41 | None |
| 35-R28 | 3 | 75 | 70 | 78 | 43 | None |
| 35-R29 | 2 | 75 | 65 | 73 | 43 | None |
| 35-R30 | 2 | 75 | 65 | 73 | 44 | None |
| 35-R31 | 2 | 75 | 65 | 73 | 49 | None |
| 35-R32 | 2 | 75 | 65 | 73 | 46 | None |
| 35-R33 | 3 | 70 | 69 | 74 | 41 | None |
| 35-R34 | 2 | 70 | 64 | 69 | 49 | None |
| 35-R35 | 2 | 70 | 64 | 69 | 46 | None |
| 35-R36 | 2 | 65 | 61 | 66 | 49 | None |
| 35-R37 | 2 | 65 | 61 | 66 | 47 | None |
| 35-R38 | 2 | 65 | 61 | 66 | 50 | None |
| 35-R39 | 2 | 65 | 61 | 66 | 46 | None |
| 35-R40 | 2 | 65 | 61 | 66 | 48 | None |

*Source:* HDR, Inc.

Analysis results indicate that noise impacts are not projected to occur under feeder bus Route 35.

## 3.4 Noise Analysis Summary

**Table 23** provides a summary of the LRT and BRT noise impacts.

**Table 23 | Summary of LRT and BRT Noise Impacts**

| | Land Use Category | LRT | | | | BRT | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Alt. 1A | Alt. 1B | Alt. 2 | Alt. 3 | Alt. 1A | Alt. 1B | Alt. 2 | Alt. 3 |
| Number of Moderate Impacts | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 1 | 3 | 9 | 4 | 1 | 1 | 2 | 2 |
| | 3 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 |
| Number of Severe Impacts | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 4 | 7 | 18 | 16 | 0 | 0 | 0 | 0 |
| | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

*Source:* HDR, Inc.

The LRT alternatives resulted in more impacts largely due to use of the audible warning systems. No impacts were found for Category 1 buildings, which were all recording studios.

# 4.0 Noise Mitigation

## 4.1 LRT Noise Mitigation

The LRT transit mode has seven noise sources included in the FTA spreadsheet model. To determine the most effective noise mitigation approach, the contribution of the individual sources must be known. **Table 24** lists the individual source sound levels for each affected receptor, as calculated using the FTA spreadsheet model.

**Table 24 | LRT Noise Impacts Attribution by Source**

| Receptor | Land Use Category | Impact | Sound Level ($L_{dn}$/$L_{eq}$ dBA) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Moderate Impact Threshold | Severe Impact Threshold | Total Project Level | Rail Transit Vehicle | Transit Warning Device | Crossing Signal | Special Trackwork (Crossovers) | VSMF | Feeder Bus Idling | Feeder Bus |
| R6 | 2 | Moderate | 58 | 63 | 61 | 61 | 0 | 0 | 0 | 0 | 0 | 0 |
| R8 | 2 | Severe | 59 | 64 | 69 | 59 | 69 | 0 | 0 | 0 | 0 | 0 |
| R9 | 3 | Severe | 60 | 66 | 67 | 57 | 66 | 0 | 0 | 0 | 0 | 0 |
| R11 | 2 | Severe | 59 | 64 | 66 | 56 | 65 | 58 | 42 | 0 | 0 | 0 |
| R12 | 2 | Severe | 59 | 64 | 66 | 56 | 65 | 54 | 0 | 0 | 35 | 0 |
| R13 | 3 | Moderate | 65 | 70 | 69 | 58 | 69 | 0 | 0 | 0 | 32 | 0 |
| R14 | 2 | Severe | 60 | 65 | 66 | 55 | 65 | 55 | 42 | 0 | 0 | 0 |
| R15 | 2 | Severe | 60 | 65 | 67 | 56 | 67 | 0 | 0 | 0 | 0 | 0 |
| R17b | 2 | Severe | 58 | 64 | 71 | 59 | 70 | 63 | 0 | 0 | 0 | 0 |
| R18 | 2 | Severe | 58 | 64 | 67 | 56 | 67 | 57 | 0 | 0 | 0 | 0 |
| R21 | 2 | Moderate | 58 | 64 | 59 | 59 | 0 | 0 | 0 | 0 | 0 | 0 |
| R22 | 2 | Moderate | 58 | 64 | 59 | 59 | 0 | 0 | 0 | 0 | 0 | 0 |
| R27 | 2 | Severe | 64 | 69 | 72 | 60 | 71 | 49 | 52 | 0 | 0 | 0 |
| R28 | 3 | Moderate | 70 | 78 | 71 | 59 | 70 | 65 | 0 | 0 | 0 | 0 |
| R33 | 2 | Moderate | 65 | 71 | 66 | 56 | 66 | 0 | 0 | 0 | 0 | 47 |
| R35a | 2 | Moderate | 65 | 73 | 70 | 59 | 69 | 64 | 48 | 0 | 0 | 42 |
| R38 | 2 | Moderate | 65 | 73 | 70 | 57 | 70 | 0 | 0 | 0 | 0 | 45 |
| R39 | 2 | Moderate | 65 | 73 | 66 | 56 | 66 | 0 | 0 | 0 | 0 | 42 |
| R40 | 2 | Moderate | 65 | 70 | 70 | 57 | 70 | 51 | 0 | 0 | 0 | 0 |
| R41 | 2 | Severe | 65 | 70 | 73 | 58 | 73 | 0 | 0 | 0 | 0 | 0 |
| R42 | 2 | Moderate | 65 | 70 | 69 | 56 | 69 | 0 | 0 | 0 | 0 | 0 |
| R43 | 2 | Severe | 65 | 70 | 73 | 58 | 73 | 0 | 0 | 0 | 0 | 0 |
| R48 | 2 | Severe | 61 | 66 | 68 | 45 | 68 | 0 | 0 | 0 | 0 | 0 |
| R49 | 2 | Severe | 61 | 66 | 76 | 53 | 76 | 0 | 0 | 0 | 0 | 0 |
| R50 | 2 | Severe | 61 | 66 | 75 | 52 | 74 | 0 | 0 | 0 | 0 | 0 |
| R51 | 2 | Severe | 61 | 66 | 70 | 50 | 70 | 0 | 0 | 0 | 0 | 0 |
| R52 | 2 | Severe | 61 | 66 | 74 | 54 | 74 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R53 | 2 | Severe | 61 | 66 | 73 | 53 | 73 | 0 | 0 | 0 | 0 | 0 |
| R54 | 2 | Severe | 61 | 66 | 76 | 53 | 76 | 0 | 0 | 0 | 0 | 0 |
| R56 | 2 | Severe | 61 | 66 | 75 | 55 | 75 | 0 | 0 | 0 | 0 | 0 |
| R62 | 2 | Moderate | 65 | 75 | 71 | 54 | 71 | 0 | 0 | 0 | 0 | 0 |

*Source:* HDR, Inc.

The individual source sound levels indicate the transit warning device yields the highest levels and is a contributing factor to every severe impact. Receivers R6, R21, and R22 experience noise from the transit vehicle alone; wheel skirts (panels that cover the wheels) may offer potential noise reduction. Receivers R8 and R17b are most influenced by the transit warning device; however, noise from the transit vehicle or crossing signal would cause moderate impacts even without the transit warning device considered. Receivers R9, R11, R12, R18, and R35a have transit vehicle or crossing signal levels within 3 dBA of the moderate impact threshold. Even if the transit warning device levels were reduced, the summed contributions could yield impacts. While important to note these specific contributions, a majority of the impacts were due to the transit warning device alone.

HDR determined that the FTA spreadsheet model overestimates the noise emissions of the HRT vehicle bell. According to HRT, the project LRT vehicle will have a vehicle bell which produces a level of 75 dBA at 100 feet. The vehicle bell would be used for ungated crossings in the median-running segments near the Oceanfront station (R41 – R56, R62, and R63). Assuming free field conditions (meaning the area is free from obstructions that could affect the way sound travels away from the noise source), this level becomes 81 dBA at 50 feet for the vehicle bell. Referencing Table 6-3 from the detailed noise analysis of the FTA guidance document (FTA 2006), a transit car whistle with a $SEL_{ref}$ of 81 dBA has an approximate $L_{max}$ of 78 dBA (both at 50 feet and 50 miles per hour). The project vehicle levels are not comparable to the FTA $SEL_{ref}$'s, so the most comparable levels are the $L_{max}$ values. The FTA spreadsheet model has a transit warning device category, which has a $SEL_{ref}$ of 93 dBA at 50 feet and 50 mph. As indicated by Table 6-3 of the FTA manual, a reference SEL of 93 dBA equates to an approximate $L_{max}$ of 90 dBA, which is louder than the level identified by HRT. **Table 25** provides a summary of the comparison between the project vehicle levels and the levels used by the FTA method.

**Table 25 | Transit Warning Device Level Comparison**

| Source | Estimated Project Level at 50 ft | Approximate $L_{max}$ at 50 ft (Table 6-3, FTA 2006) | Approximate $L_{max}$ at 50 ft (FTA Spreadsheet Model) |
|---|---|---|---|
| Vehicle Bell | 81 dBA | 78 dBA | 90 dBA |

*Source:* HDR, Inc.

The table indicates the FTA spreadsheet model overestimates the noise from the vehicle bell. Although the project vehicle bell is 3 dBA louder than the source level from Table 6-3 of the FTA manual, the FTA spreadsheet overestimates the project vehicle bell noise by 9 dBA. This overestimate of noise projected for the vehicle bell contributes to some of the calculated noise impacts. In areas where vehicle bell use is projected, the bell noise alone would cause 2 moderate impacts and 10 severe impacts. To evaluate the effect of the FTA spreadsheet model's overestimate of bell noise, the transit warning device source was changed to a lower, more realistic, value at receptors where only the vehicle bell is used in normal operations. The estimated project level of 81 dBA at 50 feet for the vehicle bell can be approximated to have a $SEL_{ref}$ of 84 dBA (based upon the 3 dBA difference between the $L_{max}$ and $SEL_{ref}$ values for the transit car whistles source from Table 6-3 of the FTA manual). The transit warning device was therefore replaced by a source with an $SEL_{ref}$ of 85 dBA (the closest available noise level). **Table 26** shows the change in impacts when the more realistic noise level is used for the vehicle bell.

**Table 26 | Vehicle Bell Source Impacts**

| Receptor | Land Use Category | Project Level ($L_{dn}$, dBA) | | Impact | |
|---|---|---|---|---|---|
| | | Overestimated Bell Noise | Realistic Bell Noise | Overestimated Bell Noise | Realistic Bell Noise |
| R41 | 2 | 73 | 64 | Severe | None |
| R42 | 2 | 69 | 59 | Moderate | None |
| R43 | 2 | 73 | 64 | Severe | None |
| R48 | 2 | 68 | 56 | Severe | None |
| R49 | 2 | 76 | 64 | Severe | Moderate |
| R50 | 2 | 74 | 63 | Severe | Moderate |
| R51 | 2 | 70 | 58 | Severe | None |
| R52 | 2 | 74 | 62 | Severe | Moderate |
| R53 | 2 | 73 | 61 | Severe | Moderate |
| R54 | 2 | 76 | 64 | Severe | Moderate |
| R56 | 2 | 75 | 63 | Severe | Moderate |
| R62 | 2 | 71 | 60 | Moderate | None |

*Source:* HDR, Inc.

When a realistic value for vehicle bell noise is used the number and severity of impacts are reduced. **Table 27** summarizes the remaining receivers with severe impacts.

**Table 27 | Receptors with Severe Impacts**

| Receptor | Land Use Category | Impact | Sound Level ($L_{dn}/L_{eq}$), dBA | | | | |
|---|---|---|---|---|---|---|---|
| | | | Moderate Impact Threshold | Severe Impact Threshold | Transit Warning Device Reduction | Crossing Signal Reduction | Project Level with Reductions |
| R8 | 2 | Severe | 59 | 64 | 8 | - | 63 |
| R9 | 3 | Severe | 60 | 66 | 2 | - | 65 |
| R11 | 2 | Severe | 59 | 64 | 6 | 0 | 63 |
| R12 | 2 | Severe | 59 | 64 | 4 | 0 | 63 |
| R14 | 2 | Severe | 60 | 65 | 3 | 0 | 64 |
| R15 | 2 | Severe | 60 | 65 | 3 | - | 64 |
| R17b | 2 | Severe | 58 | 64 | 11 | 6 | 63 |
| R18 | 2 | Severe | 58 | 64 | 6 | 0 | 63 |
| R27 | 2 | Severe | 64 | 69 | 4 | 0 | 68 |

*Source:* HDR, Inc.

**Table 27** shows the reduction in the transit warning device and crossing signal levels that would be needed to mitigate the severe impacts to a moderate level. Another option for the transit warning device could be a change in operations during nighttime hours (10:00 pm – 7:00 am). Reduced nighttime usage would reduce the project-related $L_{dn}$, which is used to assess category 2 residential receivers. To reduce noise produced by the crossing signals, consideration could be given to alternative methods of providing audible warnings such as “chirp” signals. These “chirp” signals are generally considered less intrusive on the ambient noise environment. A final option would be the use of barriers to block the path between noise sources and receivers.

These recommendations also apply to mitigation of moderate impacts. As shown in **Table 24**, moderate impacts occurred from the LRT vehicle alone, the transit warning device alone, and combined contributions of multiple sources.

### 4.2 BRT Noise Mitigation

The two moderate BRT impacts are due to the BRT vehicle itself, and BRT vehicles idling at the Oceanfront station. Mitigation measures in these cases are limited to using quieter vehicles, relocating the Oceanfront station away from noise-sensitive receptors, or blocking the transmission path between the source and receiver with barriers.

### 4.3 Feeder Bus Noise Mitigation

The analysis showed that the feeder bus routes associated with the build alternatives would not result in additional noise impacts. Therefore, no mitigation is required.

## 5.0 Vibration Impact Assessment Methodology

### 5.1 Approach

HDR used three techniques to identify vibration-sensitive land uses in the study area. First, HDR reviewed aerial photographs with the alternate alignments and bus routes overlaid upon them. Second, HDR reviewed publicly available and reasonably obtainable information on-line to look for vibration-sensitive land uses (i.e. recording studios, broadcast studios, certain medical facilities, electronics manufacturers, etc.). Third, HDR performed a windshield survey of the study area and spoke with individuals in the study area.

**Table 28** describes the land use categories for a general vibration assessment.

**Table 28 | Vibration Assessment Land Use Categories**

| Land Use Category/ Building Type | Description of Land Use Category |
|---|---|
| 1 | Buildings where vibration would interfere with interior operations |
| 2 | Residences and buildings where people normally sleep |
| 3 | Institutional land uses with primarily daytime use |
| Special | Concert halls, TV studios, recording studios, auditoriums, and theaters |

*Source:* FTA, 2006

The general vibration assessment considered each building individually. All buildings within the project area were screened to identify category 2 and category 3 buildings. Category 1 buildings and special buildings were identified on an individual basis.

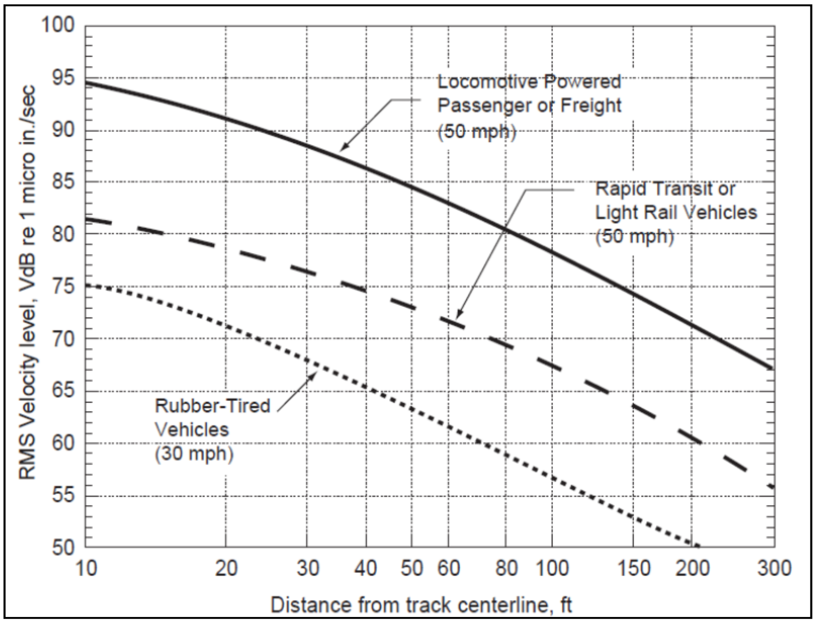
### 5.1.1 Measurement of Existing Vibration Conditions

HDR did not perform any measurements of existing vibration conditions, as existing vibration levels are not needed for the FTA's general vibration assessment.

## 5.2 Predictions of Project-Related Vibration

**Figure 12** illustrates the curves used to determine the levels of project-related vibration (Figure 10-1 of the FTA manual).

**Figure 12 | General Vibration Curves**




*Source:* FTA, 2006

Each curve represents a type of transit system; the middle curve is applied to the LRT option and the bottom curve is applied to the BRT option. Each curve is based on a certain speed and certain conditions, so adjustment factors are given in Table 10-1 of the FTA manual.

### 5.2.1 LRT Vibration Analysis

Vibration is typically assessed in one of two ways: determine the level of project-related vibration at individual buildings or building clusters, and then apply appropriate adjustments on an individual basis; or alternatively, determine the distance at which impacts would occur for each land use category, and then count the buildings within the respective distances. HDR selected the second approach for the corridor analysis.

Buildings were grouped together based on the land use categories stated in **Table 28**, and adjustment factors were applied in accordance with FTA guidelines based on buildings typical of each land use category. This process did rely on generalization, but conservative application of the adjustment factors minimized inaccuracies for unique buildings. **Table 29** provides the adjustment factors used, given in VdB[1].

[1] The FTA manual defines its ground-borne vibration (GBV) criteria using a decibel notation of the root mean square velocity amplitude. The levels are calculated using a reference velocity amplitude of $1\text{x}10^{-6}$ inches/second, and are given the units VdB.

**Table 29 | LRT Adjustment Factors for Ground-Borne Vibration (VdB)**

| Land Use Category | Speed | Vehicle Parameter | Track Conditions | Propagation Geology | Coupling to Building Foundation | Floor-to-Floor Attenuation | Floor Amplification |
|---|---|---|---|---|---|---|---|
| 1 | Varied | 0 | 0 / +10 | 0 | -7 | 0 | 0 |
| 2: Single-Family | Varied | 0 | 0 / +10 | 0 | -5 | 0 | 0 |
| 2: Multi-Family | Varied | 0 | 0 / +10 | 0 | -5 | -2 | +6 |
| 3 | Varied | 0 | 0 / +10 | 0 | -7 | 0 | 0 |
| Special: Studios | Varied | 0 | 0 / +10 | 0 | -7 | 0 | 0 |
| Special: Theaters | Varied | 0 | 0 / +10 | 0 | -7 | 0 | 0 |

*Source:* HDR, Inc.

The track alignments were divided into sections based on station to station maximum speeds. The calculation process was duplicated for speeds of 20, 25, 35, 40, and 45 miles per hour. The project would use new vehicles, so no adjustment (0 Vdb) was made for vehicle parameters. Two track conditions were considered for the LRT option: no adjustment (0 VdB) was made for straight track (wayside vibration); while 10 VdB was added for crossovers (special trackwork vibration). Local geological data was obtained and reviewed (Smith and Harlow, Jr. 2002). Loose quartz sand and quartz sand were the prevalent types of underlying soil. As these types of soil do not propagate ground-borne vibration efficiently, no adjustment was applied.

For coupling to the building foundation, residential buildings were considered to have residential construction and all other buildings were considered to be 1-2 story masonry. While many buildings larger than 1-2 story and buildings with more substantial construction are in the study area, they would have further reductions in the calculated vibration velocity level. These assumptions lead to a conservative overestimation of vibration levels for larger buildings. Multi-family dwellings have units above grade, so floor-to-floor attenuation of -2 VdB, and floor amplification of 6 VdB were applied. All other buildings were considered to be on grade.

The total net adjustment for vibration levels was determined for each category and applied to the appropriate impact criterion. The distance to potential impact was determined from the adjusted impact criteria for each land use category and for various levels of speed. Using ArcMap Geographic Information Systems (GIS) software, the distances to impact were plotted as contours (shaded areas around the alignment). Contours were created for categories 1 and 2 for the straight track, and categories 1, 2, and 3 for the crossovers. The furthest distance to a category 3 impact from the straight track was 5.3 feet, so plotting contours was unnecessary for category 3. Contours were not needed for the special buildings as the distances to impact were identical to distances for categories 1 and 2. Buildings potentially affected by vibration were located by identifying the buildings within the appropriate contours.

### 5.2.2 BRT Vibration Analysis

The BRT option is based upon the same criteria as the LRT option, but the project-related vibration levels are calculated using a different, much lower, general vibration curve. The same adjustment factors are applied, with the exception of no adjustment for special trackwork. As seen in **Figure 12**, the bottom curve used for the BRT is below the middle curve used for the LRT. The difference between the two curves is greater than 5 VdB at all distances. Both of these curves are treated with the same adjustment factors; however, they are based on different reference speeds. The following equation is used to adjust for different speeds using the reference speed of the curve.

$$Adjustment = 20 * \log(\frac{speed}{speed_{ref}})$$

Whether adjusting the BRT curve up to 50 mph from 30 mph or adjusting the LRT curve down to 30 mph from 50 mph, the adjustment level is 4.4 VdB. As the difference between the curves is at least 5 VdB, it was determined the BRT will produce less vibration than the LRT when the remaining adjustment factors are equivalent. Based on this determination, the LRT contour methodology was used as a screening process for the BRT general vibration assessment.

The BRT general vibration assessment began with the impacted buildings from the LRT assessment. No special trackwork is present for the BRT option, so the buildings only impacted by the track crossovers were removed from further consideration for BRT vibration impacts. By doing so, only buildings impacted by wayside vibration from the alignment remained. The BRT-related vibration levels were then calculated for each building individually. **Table 30** contains the adjustment factors used for the BRT option.

**Table 30 | BRT Adjustment Factors for Ground-Borne Vibration (VdB)**

| Receptor | Speed, mph | Vehicle Parameter | Track Conditions | Propagation Geology | Coupling to Building Foundation | Floor-to-Floor Attenuation | Floor Amplification |
|---|---|---|---|---|---|---|---|
| R6: Single-Family | 45 | 0 | 0 | 0 | -5 | 0 | 0 |
| R17b: Single-Family | 40 | 0 | 0 | 0 | -5 | 0 | 0 |
| R21: Single-Family West | 40 | 0 | 0 | 0 | -5 | 0 | 0 |
| R21: Single-Family East | 40 | 0 | 0 | 0 | -5 | 0 | 0 |
| Dominion Test Instruments | 40 | 0 | 0 | 0 | -7 | 0 | 0 |

*Source:* HDR, Inc.

Similar to the LRT vibration analysis, there were no adjustments required for new vehicles, paved roads, and soil conditions. The wood frame single-family homes shown in **Table 30** have a building foundation adjustment of -5 VdB, and Dominion Test Instruments, a one-story masonry building, has an adjustment of -7 VdB. Dominion Test Instruments is an at-grade structure, and the single-family homes are assumed to be at-grade, so no floor-to-floor attenuation or floor amplification is applied.

### 5.2.3 Feeder Bus Vibration Analysis

The feeder bus vibration analysis methodology generally followed the BRT methodology. Using the same adjustment factors found in **Table 29** (with 0 VdB adjustments for track conditions), the LRT methods were used to determine impact distances from the bus routes. The furthest distance to impact across the land use categories was found to be 36.6 feet, so buildings within 36.6 feet of the bus routes were analyzed individually. **Table 31** contains the adjustment factors used for the receptors within 36.6 feet of the bus routes.

**Table 31 | Feeder Bus Adjustment Factors for Ground-Borne Vibration (VdB)**

| Receptor | Speed, mph | Vehicle Parameter | Track Conditions | Propagation Geology | Coupling to Building Foundation | Floor-to-Floor Attenuation | Floor Amplification |
|---|---|---|---|---|---|---|---|
| 39-R07: Town Homes | 35 | 0 | 0 | 0 | -5 | 0 | 0 |
| 39-R40: Hotels | 35 | 0 | 0 | 0 | -7 | -2 | 6 |
| 39-R41: Hotels | 35 | 0 | 0 | 0 | -7 | -2 | 6 |
| 39-R42: Hotels | 35 | 0 | 0 | 0 | -7 | -2 | 6 |
| 39-R43: Hotels | 35 | 0 | 0 | 0 | -7 | -2 | 6 |

*Source:* HDR, Inc.

The town homes of 39-R07 are typical residential construction (-5 VdB for coupling to building foundation), and are assumed to be at grade (0 VdB for floor-to-floor attenuation and floor amplification). The hotel receptors are generally several stories high, but the 1-2 story masonry adjustment of -7 VdB is conservatively applied to account for rooms on the second floor. The second floor is again conservatively considered for floor-to-floor attenuation (-2 VdB) and floor amplification (6 VdB). Higher levels would have further reductions in vibration level.

## 5.3 Vibration Impact Criteria

The vibration impact criteria levels are based upon land use category and frequency of vibration events. The service frequencies described in the noise assessment resulted in a total number of daily LRT and BRT vibration events of 80 per direction, or 160 total events. The feeder bus service frequencies result in a total number of 36 daily vibration events.

With a total number of vibration events exceeding 70 events per 24-hour period, the LRT and BRT fall within FTA's "Frequent Events" classification (FTA 2006). The feeder buses fall within FTA's "Occasional Events" classification. **Table 32** states the relevant vibration impact criteria from Chapter 8 of the FTA manual.

**Table 32 | Ground-Borne Vibration Impact Criteria**

| Land Use Category/Building Type | GBV Impact Levels, VdB re 1 micro-inch/sec | |
|---|---|---|
| | Frequent Events | Occasional Events |
| **Category 1:** Buildings where vibration would interfere with interior operations | 65 | 65 |
| **Category 2:** Residences and buildings where people normally sleep | 72 | 75 |
| **Category 3:** Institutional land uses with primarily daytime use | 75 | 78 |
| **Special:** Concert Halls, TV Studios, and Recording Studios | 65 | 65 |
| **Special:** Auditoriums and Theaters | 72 | 80 |

*Source:* FTA, 2006

The criteria indicate the level where a building would be considered impacted by vibrations from the transit systems, and are largely based on human perception.

## 6.0 Vibration Impact Assessment

Using the stated criteria and methodology for calculating project-related vibration levels, the alignment and vehicle alternatives were assessed to determine their respective potential for vibration impacts. The vibration criteria were drawn from Table 32, based on the land use category. Vibration levels were predicted using the methodology stated in Section 5.

### 6.1 LRT Vibration Analysis

**Table 33** contains the results of the general vibration assessment for the LRT alternatives.

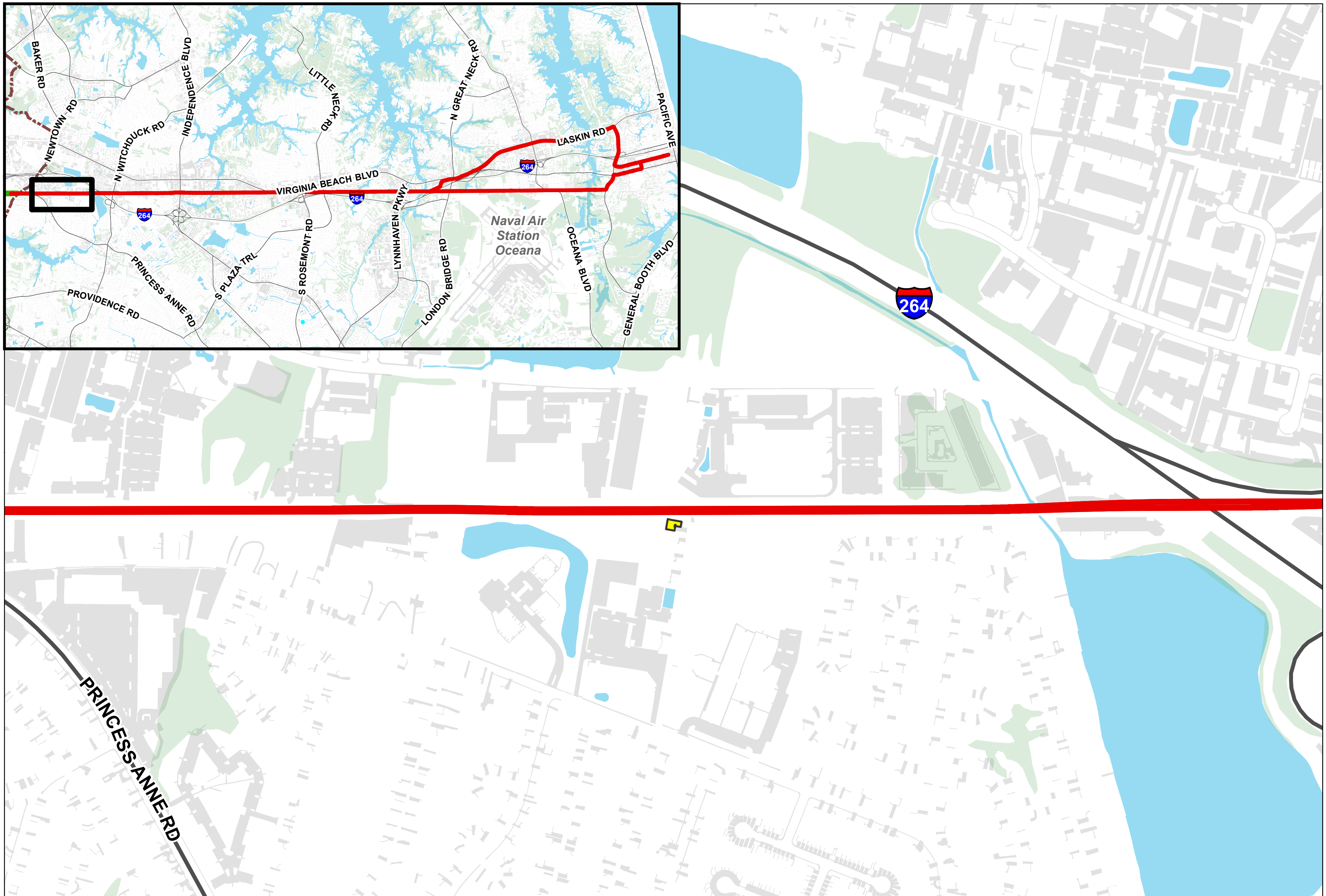
**Table 33 | LRT General Vibration Assessment Results**

| Land Use Category | Number of Building Impacts | | | |
|---|---|---|---|---|
| | Alternative 1A | Alternative 1B | Alternative 2 | Alternative 3 |
| 1 | 0 | 0 | 1 | 1 |
| 2 | 7 | 10 | 20 | 20 |
| 3 | 0 | 0 | 0 | 0 |
| Special: Studios | 0 | 0 | 0 | 0 |
| Special: Theaters | 0 | 0 | 0 | 0 |

*Source:* HDR, Inc.

The locations of the impacted buildings are shown in **Figures 13 through 19**.

For category 1, there was one building identified as a possible impact; the remaining impacts were residences within category 2. A majority of the impacts were due to crossovers, which produce increased vibration levels.




0 0.1 0.2 Miles

1 inch = 0.12 miles

**Legend**

Locations of Impacted Buildings

**Figure 13 | Locations of Buildings with Potential Vibration Impacts**

N W E S

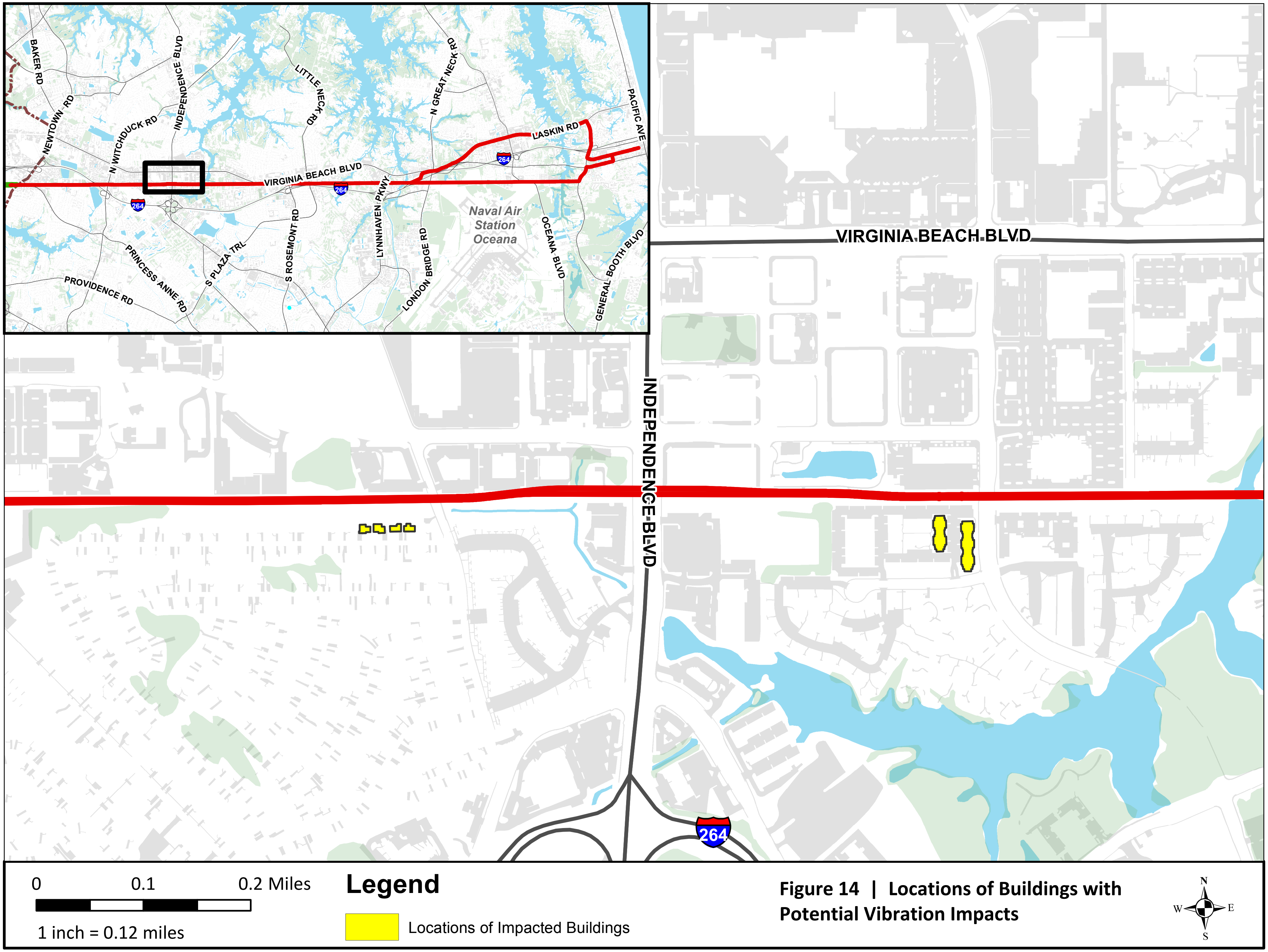
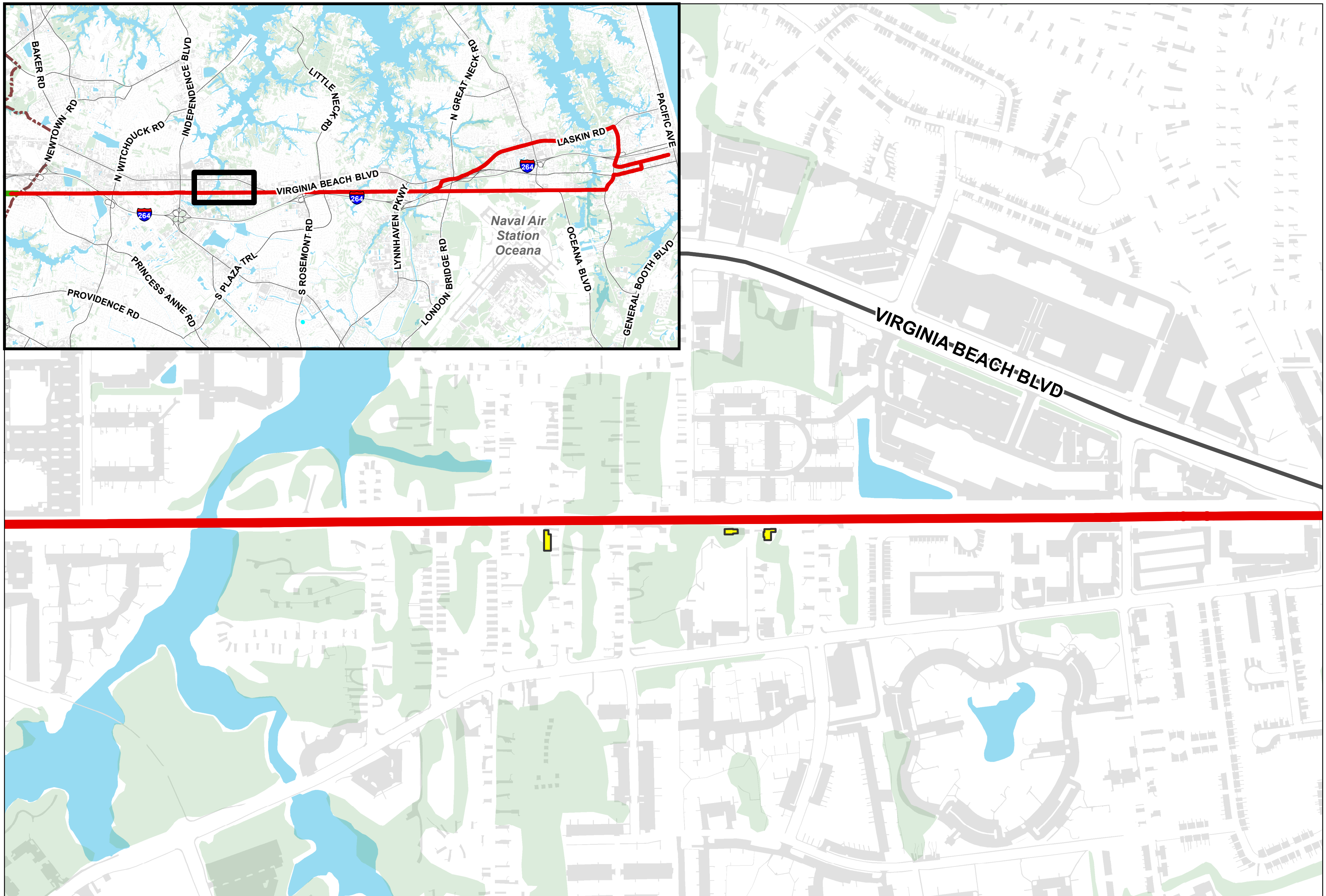


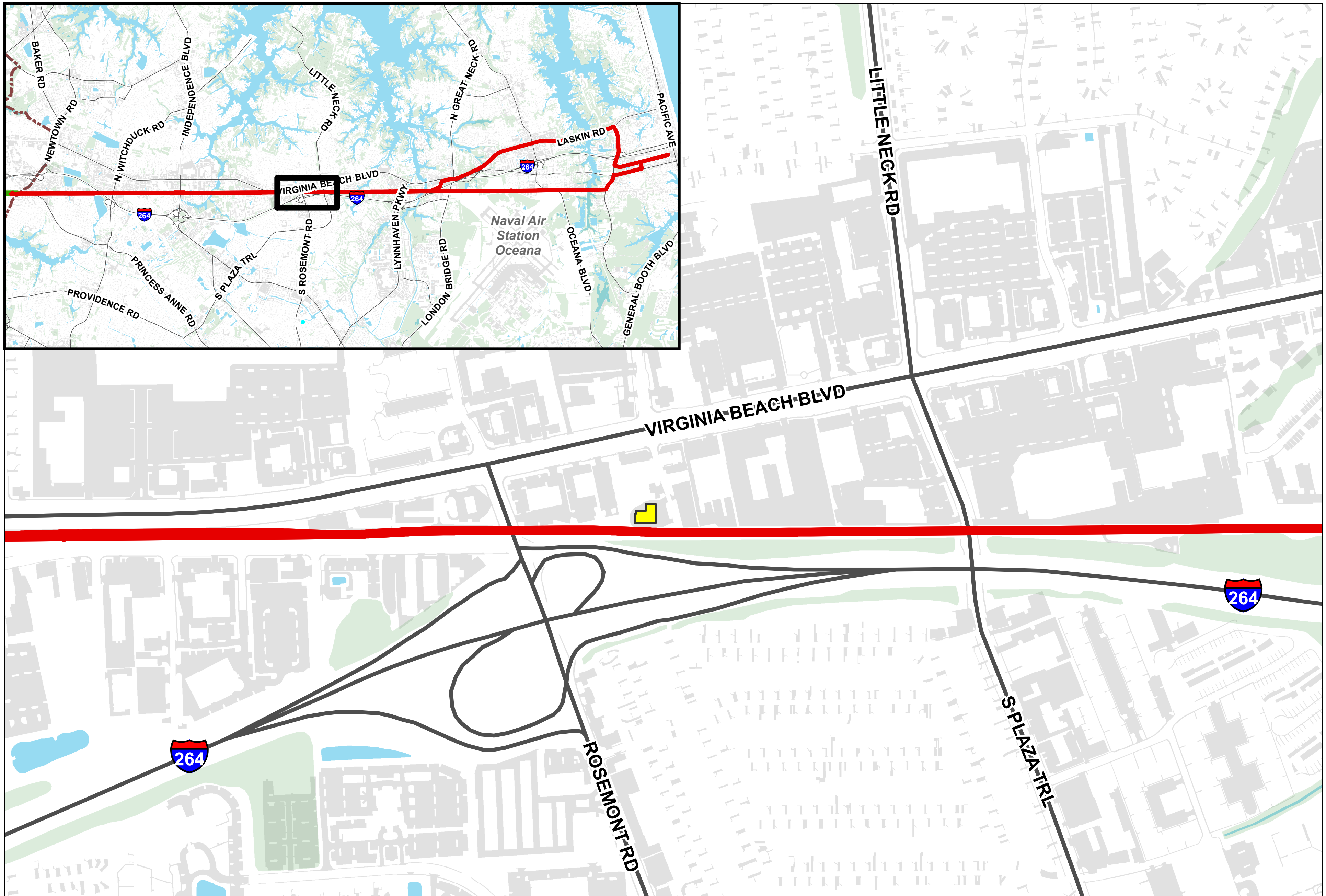

**Figure 14 | Locations of Buildings with Potential Vibration Impacts**




## Legend

Locations of Impacted Buildings

**Figure 15 | Locations of Buildings with Potential Vibration Impacts**




0 0.1 0.2 Miles

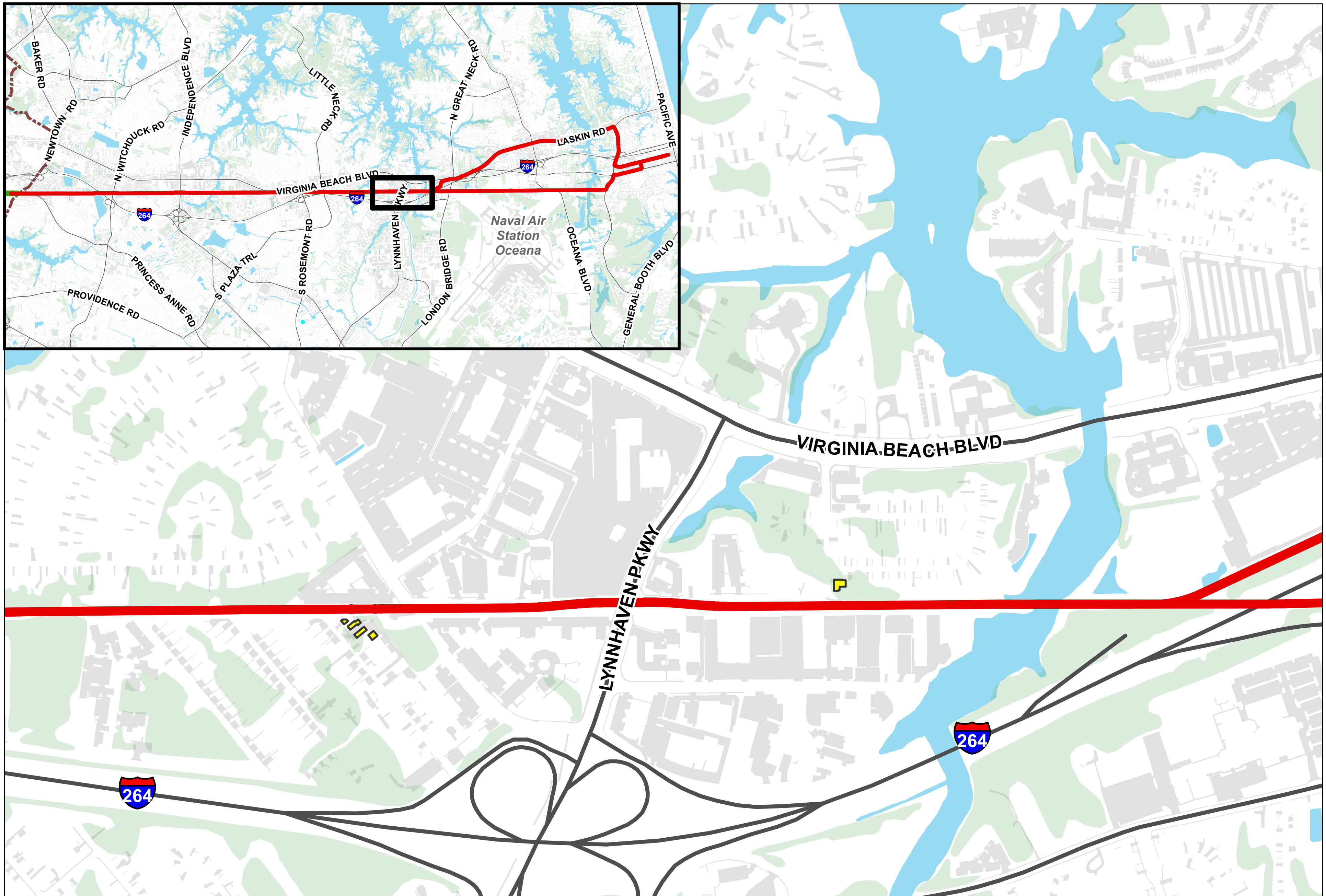
1 inch = 0.12 miles

**Legend**

Locations of Impacted Buildings

**Figure 16 | Locations of Buildings with Potential Vibration Impacts**

N E S W



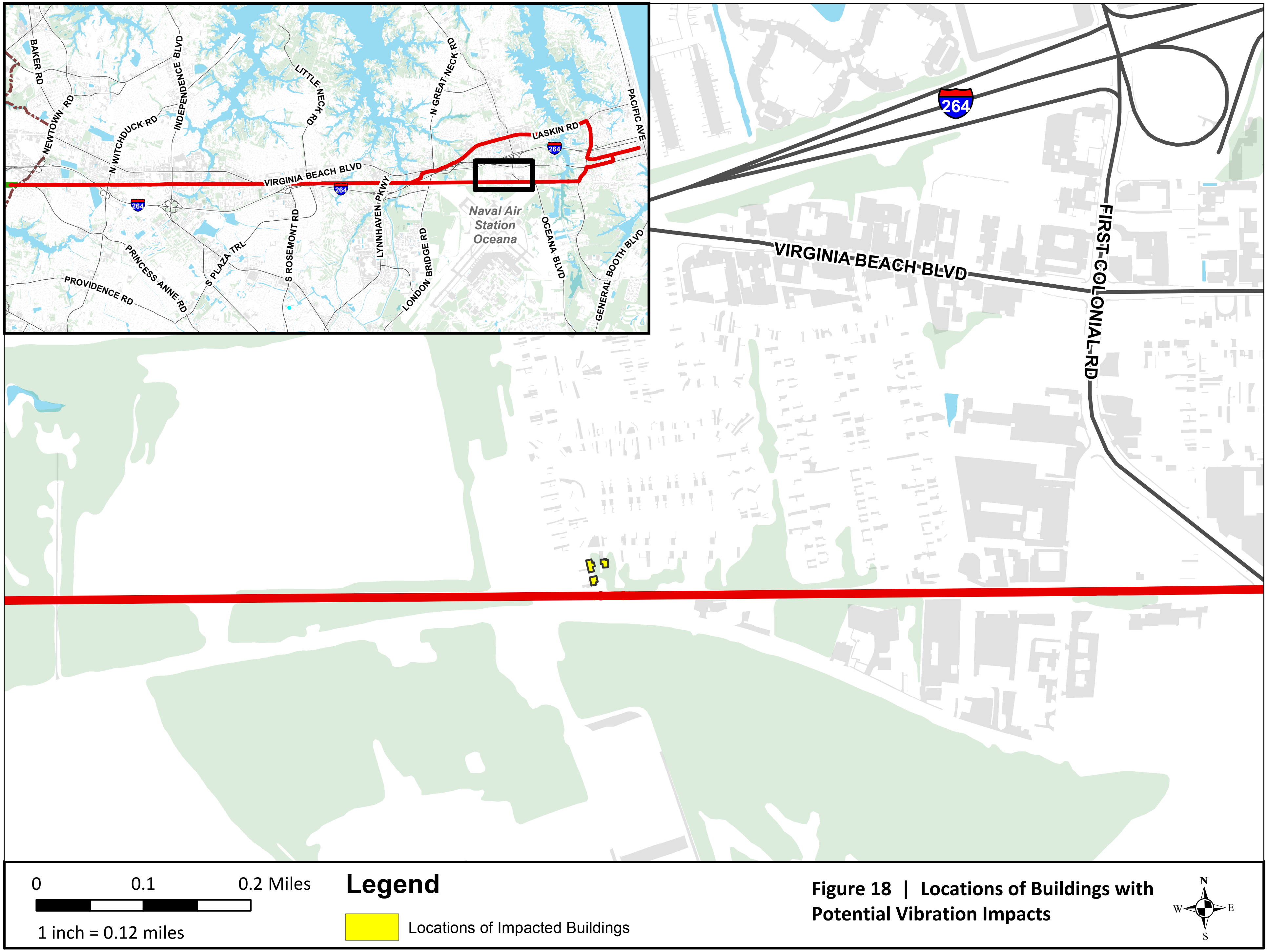

0 0.1 0.2 Miles

1 inch = 0.12 miles

**Legend**

Locations of Impacted Buildings

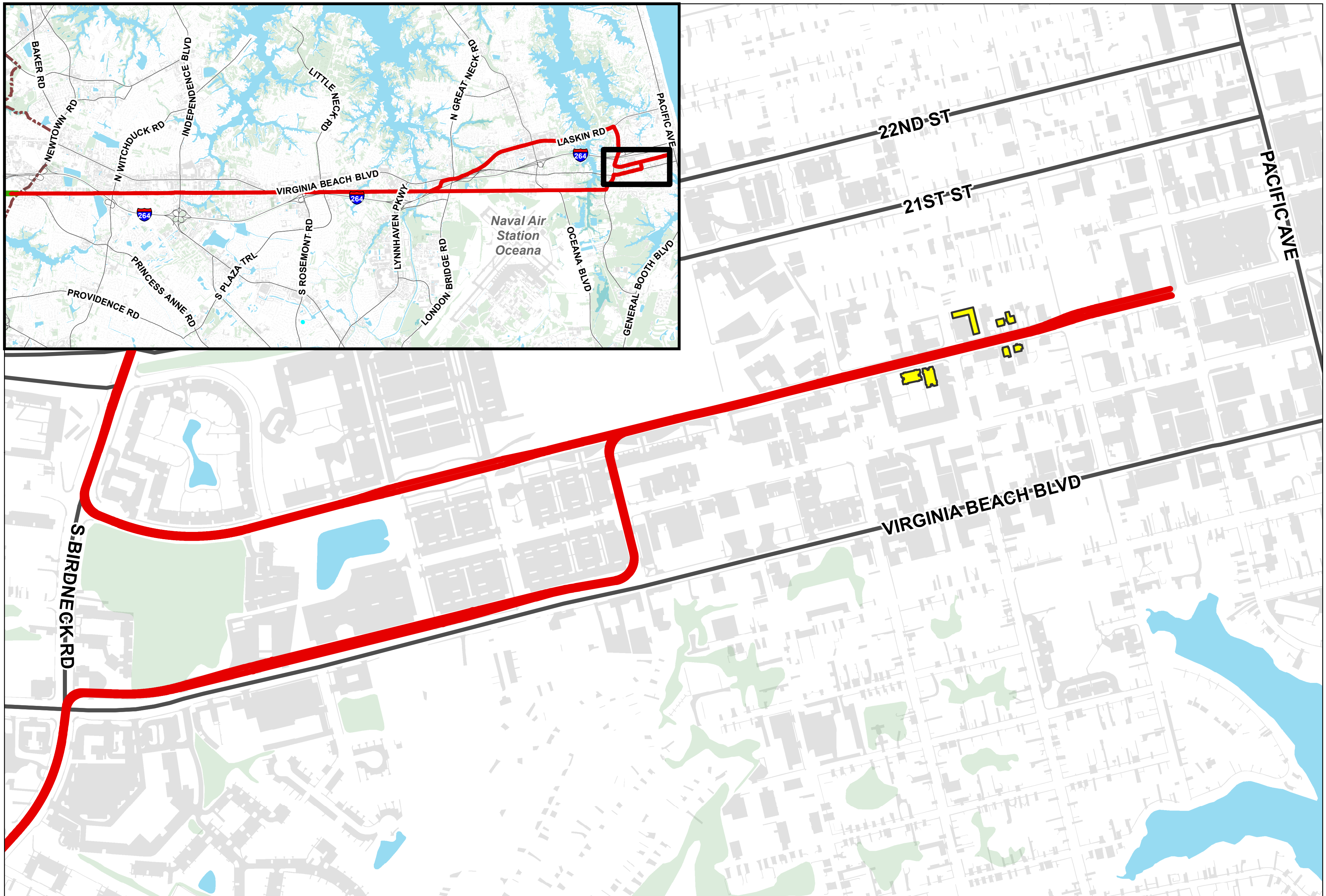
**Figure 17 | Locations of Buildings with Potential Vibration Impacts**




## Legend

Locations of Impacted Buildings

**Figure 18 | Locations of Buildings with Potential Vibration Impacts**




0 0.1 0.2 Miles

1 inch = 0.12 miles

**Legend**

Locations of Impacted Buildings

**Figure 19 | Locations of Buildings with Potential Vibration Impacts**

N E S W

## 6.2 BRT Vibration Analysis

**Table 34** contains the results of the general vibration assessment for the BRT option.

**Table 34 | BRT General Vibration Assessment Results**

| Land Use Category | Number of Building Impacts | | | |
|---|---|---|---|---|
| | Alternative 1A | Alternative 1B | Alternative 2 | Alternative 3 |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| Special: Studios | 0 | 0 | 0 | 0 |
| Special: Theaters | 0 | 0 | 0 | 0 |

*Source:* HDR, Inc.

There are no vibration impacts from any of the BRT alternatives.

## 6.3 Feeder Bus Vibration Analysis

**Table 35** contains the results of the general vibration assessment for the feeder bus routes.

**Table 35 | Feeder Bus General Vibration Assessment Results**

| Land Use Category | Number of Building Impacts | | |
|---|---|---|---|
| | Route 38 | Route 39 | Route 35 |
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 |
| Special: Studios | 0 | 0 | 0 |
| Special: Theaters | 0 | 0 | 0 |

*Source:* HDR, Inc.

There are no vibration impacts for the feeder bus routes, so no impacts are added to the alignment alternative totals.

# 7.0 Vibration Mitigation

## 7.1 LRT Vibration Mitigation

For the LRT alternatives, **Table 36** provides a breakdown of the impacts by wayside vibration from the tracks and special trackwork vibration from the turnouts and crossovers.

**Table 36 | LRT Vibration Impacts Attribution by Source**

| Land Use Category | Alternative 1A | | Alternative 1B | | Alternative 2 | | Alternative 3 | |
|---|---|---|---|---|---|---|---|---|
| | Wayside Impacts | Special Trackwork Impacts | Wayside Impacts | Special Trackwork Impacts | Wayside Impacts | Special Trackwork Impacts | Wayside Impacts | Special Trackwork Impacts |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| 2 | 1 | 6 | 4 | 6 | 4 | 16 | 4 | 16 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Special: Studios | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Special: Theaters | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Source:* HDR, Inc.

From **Table 36**, it is clear that special trackwork (turnouts and crossovers) yielded a majority of the vibration impacts. Special trackwork vibration could be mitigated by moving the crossovers away from vibration-sensitive receivers. Other methods of mitigation could include high-resilience fasteners, ballast mats, floating slab trackbeds, and resiliently supported ties.

### 7.2 BRT Vibration Mitigation

No vibration impacts were found for the BRT option, so mitigation measures are not needed.

### 7.3 Feeder Bus Vibration Mitigation

No vibration impacts were found for the feeder bus routes, so mitigation measures are not needed.

## 8.0 Construction Noise and Vibration

Construction-related activities produce short-term noise and vibration. Typical noise emission levels for construction equipment are given in Table 12-1 of the FTA manual, and typical vibration source levels for construction equipment are given in Table 12-2 of the FTA manual (FTA 2006).

### 8.1 Construction-Related Noise

For general assessment purposes, the FTA offers non-standardized noise criteria for evaluating the combined noise levels of the two loudest pieces of construction equipment. **Table 37** summarizes the noise criteria.

**Table 37 | FTA Non-Standardized General Construction Noise Criteria**

| Land Use | One-hour $L_{eq}$, dBA | |
|---|---|---|
| | Daytime | Nighttime |
| Residential | 90 | 80 |
| Commercial | 100 | 100 |
| Industrial | 100 | 100 |

*Source:* FTA, 2006

## 8.2 Construction-Related Vibration

As construction is a relatively short-term event, damage caused by construction vibration is a greater concern than annoyance caused by construction vibration. **Table 38** provides the vibration damage criteria as stated in the FTA manual. The peak particle velocity (PPV) is the maximum of the vibration signal.

**Table 38 | Construction Damage Vibration Criteria**

| Building Category | PPV, in/sec | $L_v$, VdB |
|---|---|---|
| Reinforced concrete, steel or timber | 0.5 | 102 |
| Engineering concrete and masonry | 0.3 | 98 |
| Non-engineered timber and masonry | 0.2 | 94 |
| Buildings extremely susceptible to vibration damage | 0.12 | 90 |

*Source:* FTA, 2006

## 8.3 Construction-Related Noise and Vibration Mitigation

Construction activities should be limited to daytime hours, to minimize potential sleep disturbances. All equipment used during the construction process should be properly maintained, with mufflers that perform as well or better than the original mufflers provided by the manufacturer. A thorough construction noise and vibration analysis will be prepared for the preferred alternative. As necessary, noise and vibration mitigation measures will be evaluated at that time.

# 9.0 References

"Code of the City of Virginia Beach, Virginia." Municode. Web. 06 Nov. 2013. <http://library.municode.com/index.aspx?clientId=10122>.

*Quantities and Procedures for Description and Measurement of Environmental Sound. Part 3: Short-term measurements with an observer present*. ANSI/ASA S12.9-1993/Part 3.

Smith, Barry S., and George E. Harlow, Jr. *Conceptual Hydrogeological Framework of the Shallow Aquifer System at Virginia Beach, Virginia*. Water-Resources Investigations Report 01-4262. Richmond, VA: U.S. Department of the Interior, U.S. Geological Survey, 2002. Print.

*Transit Noise and Vibration Impact Assessment*. Washington, DC: U.S. Department of Transportation, Federal Transit Administration, Office of Planning and Environment, 2006. Print.